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Institute and Related Activities

Test and Investigations on Extra High-Tension Insulators

From a Purchasing Engineer's Point of View, with Special Reference to Methods of Test for Acceptance, Tests for Porosity and Deterioration.

BY C. COLERIDGE FARR
Prof. of Physics, Canterbury College, University of N. Z.

and

HENRY E. R. PHILPOTT
Associate, A. I. E. E.
Testing Engineer, Lake Coleridge Electric Power Supply, Christchurch, N. Z.

Review of the Subject:—*Owing to repeated failures (the number of which increased as time went on) of 66,000-volt transmission line insulators (pin type) of the first Hydroelectric undertaking, carried out by the New Zealand Government, in 1914, and having in mind that Hydroelectrical Power was to be developed to the utmost of the Dominion's power resources—of which there are many—the investigations contained herein were commenced at the suggestion of Mr. E. Parry, B. Sc. M. I. E. E. late Chief Electrical Engineer to New Zealand Government, and has been continued for the past five years with the sanction and support of Mr. L. Birks, B. Sc. M. I. E. E. Chief Electrical Engineer to New Zealand Government, with a view to ascertaining the cause of such failures.*

It is the purpose of the paper to show

1. To what extent deterioration has set in on the 66,000-volt line referred to.

2. That the cause is due to the fact that the insulators were initially porous.

3. That tests at present in vogue with regard to ascertaining the porosity of insulator porcelain are totally inadequate, as the authors consider, immersion of the complete unbroken insulator under a pressure ranging from 1500 to 2000 lb. and the total amounting to 250,000 to 300,000 lb-hours the least that will give reliable results.

4. That non-porous insulators can be made that will remain good in service for an indefinite period and withstand perfectly the tests for porosity as recommended.

5. That individual testing with high frequency seems to be the only reliable method for testing for dielectric strength.

6. That a percentage test of each batch of insulators by the maker is unsatisfactory, because unless each shell of each insulator, in the case of pin insulators, and each disk in the case of suspension insulators, is definitely flashed over before being put to service, then breakdown trouble seems bound to ensue.

7. There is room for more cooperation between the insulator manufacturer and the purchasing engineer in regard to acceptance tests and the handling and maintaining of the insulator in service. If manufacturers will not agree to the tests as recommended by the authors, being made in the factory, then in countries such as this (New Zealand) which is situated so many thousands of miles from the point of manufacture, a public testing bureau should be established where undertakings could be arranged for, such tests to be made as described herein, when the cost of replacing the failures should be borne by the manufacturers.

8. That it has been found in New Zealand we have the necessary materials from which insulators can be and are being made, that will withstand the tests described equal to the imported wares.

CONTENTS

In this paper we propose to give an account of some investigations which we have carried out in conjunction with the Public Works Department of New Zealand, with a view to obtaining some definite information regarding the causes of insulator deterioration in connection with the Lake Coleridge electric power supply system. It is hoped that this may be of some service to those interested in the insulation of extra-high-tension transmission lines, which are to play such an important part in the hydroelectric development of this Dominion in the future.

It is the experience not only in New Zealand but in other undertakings abroad, that the problem of producing an insulator that will successfully withstand both electrical and mechanical stresses for an indefinite period, without deterioration or destruction, is one of the most difficult in connection with the transmission and distribution of electrical energy at extra high tension.

It is proposed to describe in detail the tests and the results of these tests, on several types and makes of insulators, including those of British, American (U. S. A. and Canadian), New Zealand, Australian, and German manufacture.

It is desirable to state briefly how the authors came to deal with such a variety of makes.

Considerable experience has been obtained with insulator failures on the Lake Coleridge electric power

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transmission line in this country, and at one time during the late war the position due to repeated failures became so acute that it was found necessary to purchase any makes available, having in mind that these investigations were about to be made. It was hoped that a careful investigation would demonstrate the best type and quality of insulator to withstand the requirements of the heavy duty called for, involving dielectric strength, mechanical strength and durability.

Fig. 1—Showing High-Frequency Oscillator and Samples of Punctured Insulators

The apparatus employed consisted of:

(1) A 1000-volt 2000-megohm megger set.

(2) A 20-kv-a. 100,000-volt 50-cycle single-phase testing transformer with a double-scale 100,000-volt and 50,000-volt Kelvin electrostatic voltmeter.

(3) A General Electric Co. high-frequency oscillator set, capable of impressing 175,000 volts with spark gap for voltage measurements (See Fig. 1.).

(4) In the hydrostatic pressure tests for porosity, a steel testing vessel with cast iron ends capable of containing a complete insulator of the largest size, and of withstanding a pressure of 2500 lb. per sq. inch, with a high-pressure compressor capable of working up to this pressure (Fig. 2).

The electrical tests were carried out at the Public Works Department test room at Addington, Christchurch, and the porosity tests at the Physical Laboratory, Canterbury College, Christchurch. For the latter purpose the special high-pressure vessel mentioned above was provided from a research grant received from the New Zealand Institute, the assistance of which is hereby acknowledged.

A detailed account of the vessel may be given, as it was eminently successful. After pumping up to a pressure of, say, 2200 lb. per square inch, it would frequently retain the pressure so well that it had not fallen below 1500 lb. per sq. inch in four days, although no further pumping had been done in the meantime.

A hollow piece of cast steel 15 inches in internal diameter, 19 inches in external diameter and 20 inches long, was turned at both ends, and a narrow spigot was left about ¼ inch from the inner edge and running round each end. This spigot was 3/8 inch high and about 3/16 inch wide. The spigot fitted with a corresponding groove in the covers which was ½ inch deep. The groove and spigot were of such a width that a piece of leather sewing machine belting fitted the groove exactly in width. When the end pieces were screwed down, the spigot was seated upon the leather belting and made a satisfactory joint. The end pieces or covers were of good cast iron eight inches thick, and held on by 12 bolts each 2 inches diameter. When the pressure was first applied at about 800 lb. per sq. inch, it was seen that moisture was "weeping" through the bottom cover, but this righted itself probably by internal corrosion and no further trouble was experienced.

An illustration of this testing vessel is shown in Fig. 2.

Under this test the amount of penetration is apparently proportional both to the hydrostatic pressure attained, measured in lb. per sq. inch and to the time of immersion. The authors, therefore, propose to measure the intensity of the test by the product of these two factors or by the "pound-hours" to which a square inch of the insulator has been subjected.

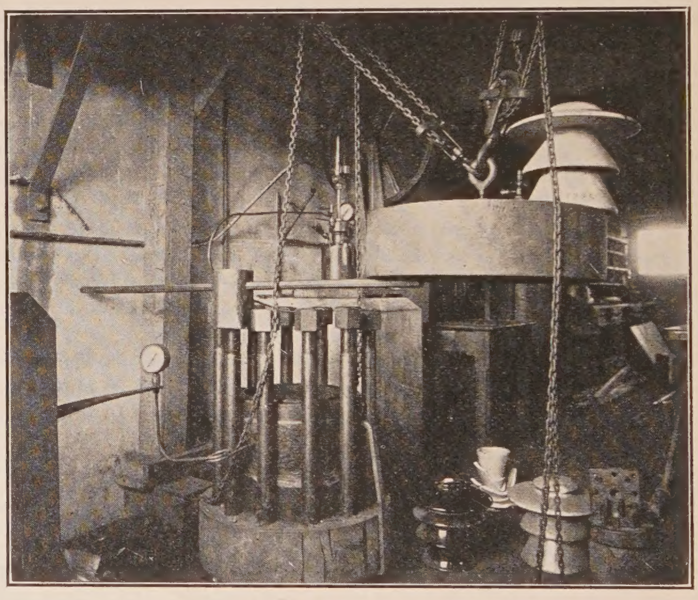

Fig. 2—Showing Large Porosity Vessel used for the Tests Described Herein, also the Small Vessel in Right Corner used for the Earlier Tests

The usual test adopted was at a pressure of 1500 to 2000 lb. per sq. inch applied for a period of seven days, *i. e.* for 250,000 to 300,000 pound-hours. We wish to insist strongly that the intensity of the porosity test to be of any value should be of this order. One important firm claims credit for its insulators because they will withstand a porosity test at a pressure of 200 lb. for 24 hours—*i. e.* 4800 pound-hours! In view of the prolonged exposure to the weather to which the

insulators are subjected in service, although only at atmospheric pressure, we consider that such a test is totally inadequate, in fact that any porosity test of less than 200,000 pound-hours is comparatively useless.

With regard to the efficiency of testing with high-frequency oscillations as compared with low or working frequency, the former gives, in the authors' opinion, much the more searching and reliable results.

After the Lake Coleridge 66,000-volt transmission line had been in service about two years, the insulator failures became so frequent that it was decided to test each insulator of the remaining stock of 500 individually, so as to insure that those used to replace the failures were reliable and good, and for this purpose the high-frequency oscillator was used.

The original consignment of insulators was imported in 1913 and this stock of 500 replace insulators was obtained in 1915 and stored in the open. They had of course withstood the makers' factory tests, but on being retested two years after delivery, during which they had been exposed to the weather in the works yard, no less than 43 or 8.5 per cent were found by individual tests to be defective. In several cases these insulators were of porous material, and had absorbed moisture during the period they had been in stock, as was proved subsequently.

Each of these replace insulators as it was tested, was numbered and its position on the lines when put into service was recorded, and although over five years have elapsed since these precautions were commenced, and over 200 breakdowns due to insulator failures have occurred, and over 500 insulators have been replaced, not one of the tested insulators has yet given trouble, which shows the efficacy of the method of testing individual insulators after they have been exposed to the weather in stock for a couple of years, thus weeding out porous ones. The main cause of deterioration of the insulators that did fail was apparently absorption of moisture, and if porous insulators are detected and excluded, insulator deterioration will largely diminish.

It seems to be the practise of some makers to test insulators with a set pressure at working frequency, from head to pin, and from these results to pass the batch or otherwise. We consider that this method is unsatisfactory, inasmuch as the faulty shells will not betray themselves (being protected by the good ones) unless each shell is individually flashed.

Further, this flashing should be done by high-frequency pressure, for the authors' experience has been that, where insulators have been guaranteed by the makers, as tested at a certain pressure, at low or working frequency, they have failed decisively when tested with the high-frequency oscillator at many thousands of volts below the guarantee. Others have withstood the pressures named by the makers *from head to pin* on both high and low frequency; but on individual testing of the shells, some were apparently mechanically perfect, but electrically were almost conductors, as will be seen later in the description of tests.

Methods of Test

The following program of tests was adopted:

(1) Measure insulation resistance of each shell with 1000 volt megger;

(2) Subject each shell separately to bare flash-over pressure at 50 cycles (working frequency) for 15 seconds;

(3) Subject each shell separately to bare flash-over pressure at high frequency for 15 seconds (Fig. 1);

(4) The complete unbroken insulator was placed in the porosity testing vessel and covered with a strong aqueous solution of fuchsin (Fig. 2). A hydrostatic pressure of 2000 lb. per sq. inch was then put on the vessel, and the insulator remained immersed in the fuchsin solution under a pressure ranging from 1500 to 2000 lb. per square inch for about a week, that is, until the number of pound-hours had reached 250,000 or 300,000.

As soon as convenient after removal from the porosity vessel the electrical tests were repeated, after which the insulator was broken up for signs of penetration. If the samples submitted withstood this complete set of tests without breakdown or signs of penetration, the batch was considered satisfactory.

It is worthy of note that of twelve makes tested, samples of seven failed to pass the tests, which shows the necessity for special acceptance tests in all cases.

It was impossible with the apparatus at our disposal to subject more than a very few individual insulators of any make to the hydrostatic pressure test for porosity. Some of the insulators so tested have been chosen to ascertain the cause of certain weaknesses previously known to exist; and the weaknesses have generally been found to be due to, or at least associated with, a band of porous material in the body of the porcelain. We consider, therefore, that if any of the few insulators in any batch that may be submitted for test are found to be porous, the whole of the batch should be rejected, and the maker informed that a repetition of such an experience would seriously jeopardize his chance of securing future contracts.

Megger Tests

While the megger test has its limitations, yet it seems to be advantageous in connection with the hydrostatic pressure tests; in that, after the insulator has been under the hydrostatic pressure, it is possible to obtain with the megger definite indication of the condition of the shells; but the greatest care must be taken when testing with the megger, for not only the humidity of the atmosphere, but even the handling of the insulator or the megger leads, will often tend to lead to wrong conclusions.

When testing insulators with the megger—dry as received—it has been noted with a dry contact, however thorough, that results are by no means consistent, as it is

almost impossible to "wipe" the whole of the surface of the joints between shells with the contact lead, and if any portion is missed, a puncture path or porous spot may also have been missed owing to the high resistance of dry cement.

It has therefore been found essential to cover the cement joints to a depth of about 1/16th of an inch with weak acid, which gives a sure contact over the whole area of the cemented joint, and more consistent results are obtained. But if high-frequency tests are to follow, the results of the high-frequency tests are likely to be misleading, unless the joints are thoroughly cleaned, because the oscillator cannot supply the C^2R losses due to dampness without undue voltage drop and probably the voltage would not reach flash-over owing to the poor regulation of the oscillator.

Humidity of the air, and human handling, are important factors when testing insulators with the

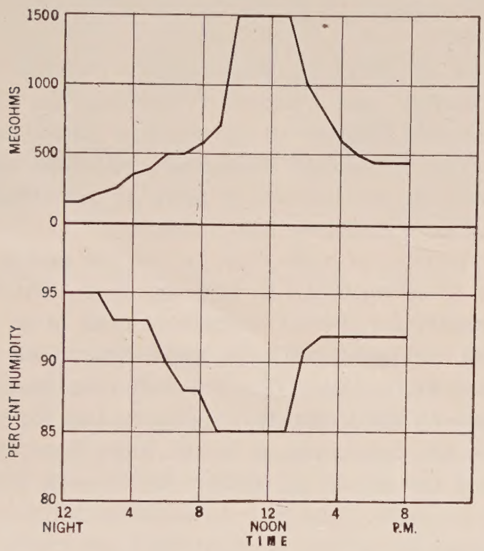

Fig. 3—Insulation and Humidity Curves—66,000-Volt Pin Insulator

megger, and it is therefore only on the driest of sunny days that megger tests should be attempted.

The curves in Fig. 3 give the results of megger tests on an insulator over a period of 20 hours during a day in early spring, and show that, in this latitude, it would not be reliable to test insulators with a megger outside the hours of 10 a. m. and 2 p. m. during certain seasons, or that megger tests should not be conducted when the percentage of humidity is much over 85.

It would seem therefore, that where, owing to porosity, the insulator may be a partial conductor, as for instance an old insulator which has been in service some years, and with no other means of test at hand, the megger may be used to advantage, but with recently made insulators, being tested for acceptance, the megger test could be dispensed with. Factory inspection has reached a stage in which faulty insulators, that could so easily be detected, would surely never leave the factory.

High-Tension Tests at Working Frequency

When no other means are available, this method—provided each shell is separately tested to flash-over—is useful.

This can be arranged where working pressure is available, and, provided each shell is tested separately at working pressure, the aggregate flash-over of the whole insulator may be assessed.

To subject an insulator to working pressure, applied from head to pin, as an acceptance test is misleading, and the results are of practically no value. It will find those which are defective in all shells—a state of affairs hardly to be expected with the present-day makes of insulators—but it will not betray any single shells that are faulty; and if there are any such, the seeds of trouble for the transmission line are sown.

A section of three miles of the Lake Coleridge transmission lines runs in duplicate alongside a steam railroad. After two years' service, 12 insulators were taken down at random for testing purposes. In every one of these 12 insulators the inner shell of the four was completely coated with a black deposit, and a test showed the shells so covered to be conductors, and hence it can be reasonably assumed that the factor of safety of all insulators near the railroad was reduced by 25 per cent, due to this deposit. With mechanical troubles developing on the top shell, due to cable loading, cable clamps, etc., the factor of safety is still further reduced, and if there happen to be one or two bad shells coupled with a mild surge due to switching or dropping of load, the insulator will break down so much earlier.

It is noteworthy that 47 or 19.8 per cent of the number (264) along the line of railroad have failed or had to be replaced during six years. A few of the breakages were mechanical but it is most probable some of the shells were "electrically down" before being put on the line.

On one occasion, about one-half mile from the railroad section, a single inner or fourth shell insulated the line for eight hours, the other three having punctured decisively.[1] This certainly could not have taken place on the railroad section, where each fourth shell was coated as described.

It therefore appears that it is absolutely essential that all shells must be tested individually.

Tests with High-Frequency Oscillator (Prof. E. E. F. Creighton's Method)

Where this apparatus is available, it has been found to be more effective in detecting faulty insulators, provided they are dry and non-porous, but as stated previously, to test from head to pin, by running up to the full capacity of the oscillator set, is very misleading, although if two or more shells are "down" (which is hardly likely with the modern makes of insulators), then indications will be quite clear.

1. Birks & Ferguson, N. Z. *Journal of Science*, Vol. 3, No. 4, page 184.

If a 300,000-volt set is available, then head to pin tests could be resorted to in order to save time, but it would still be very necessary to note that each shell must definitely flashover.

With the present-day makes of insulators, where perfect vitrification is aimed at, the megger and low or working frequency tests could be safely discarded in favor of testing individual shells by high frequency, combined with a percentage subjected to the hydrostatic pressure tests for porosity, for it has been found that where other methods have proved doubtful and some even shown the insulator to be apparently sound, the high-frequency pressure has shown them to be "down" at a comparatively low voltage.

Some engineers are doubtful as to the advisability of subjecting insulators to "flashover" on high frequency before being put to service, fearing undue stress resulting in possible damage.

Local experience tends to show that insulators so tested are quite undamaged, for upwards of 1000 insulators have been so tested (*i. e.* each shell up to flash-over on high frequency for 15 seconds) and as previously stated, over 500 have been put on the lines referred to and, although nearly five years have elapsed since the first replacement was made and over 200 breakdowns have occurred, not one of those so tested has yet failed electrically. One had to be replaced owing to damage due to rifle fire, but although mechanically damaged it was electrically as good as the day it was placed in service.

The authors have a special insulator, which has been used for hundreds of demonstrations of Creighton's Super Spark Potential Test[2]; and a certain suspension insulator which supports the high-tension lead of the high-frequency oscillator, receives full punishment every time the set is used, yet both these insulators are apparently quite undamaged. Such authorities as Creighton,[3] "consider that such tests are quite mild, and correspond to a rare case of switching and further are nothing more than the insulator may get in operation in due time;" and Peaslee,[4] states, "accumulated evidence of a large number of tests, covering combined electrical and mechanical tests, fatigue tests, and high-frequency tests, indicates such stressing has no effect whatever upon the properties of the insulators."

Many suggest, for safety, taking each shell up to bare working pressure only, but the authors have found in seven instances at least a pin hole or other fracture at or about 1 in. from the edge of the shell which it did not betray itself at bare working pressure, but at approach of flashover, the arc concentrated at the point of fracture, and in less than one minute the shell cracked. These would have been passed on a bare working pressure test.

The authors are therefore of opinion that it is absolutely essential to see that each shell should withstand flashover pressure at high frequency for at least 15 seconds continuously.

Deterioration

On the Lake Coleridge transmission lines there are over 5000 insulators and over 800 or 16 per cent have had to be replaced in six years, either owing to failure in service, or to patrolmen's observations of mechanical defects, and our experience indicates that this is due mainly to initially porous insulators, coupled with mechanical weakness.

We have found from experiment and experience that porcelain can be made which is nonporous to the limit of the somewhat severe tests we have applied, and in that case, moisture will not get into it, whether the insulator be in service or otherwise.

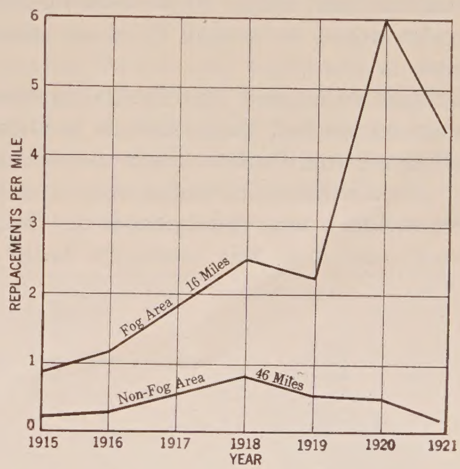

Fig. 4—Curves Showing Insulators Replaced on Transmission Lines

Curves are shown in Fig. 4 giving the numbers that have failed in a fog or mist area, and we consider that there is no doubt that the cause is due to porous insulators, absorbing moisture to such an extent as to render some shells practically conductors, when attacked by high-frequency surges or even at working pressure.

No doubt many other bad insulators are on the lines in other areas, where fog or mist is not prevalent, and in course of time these will be weeded out by breaking in service.

The diameter of the capillary tubes in even the most porous insulators we have tested is extremely small. In the first experiment we used fuchsin as the coloring agent, by which the penetration could be traced. Finding however, some difficulty in photographing the color, though it was strongly visible, we discarded it for the time being for red ink, or rather a solution of red ink powder in water. It was noticed, however, that it seemed extremely difficult to force the red ink into

2. Creighton, Insulator Testing, A. I. E. E. Journal, May 1915, page 765.

3. Creighton, Insulator Testing, A. I. E. E. Journal, May 1915, page 766.

4. Peaslee, W. D. A., Insulator Porc., A. I. E. E. Journal, Vol. XXXIX No. 5, page 445.

the porcelain. A faint coloration was frequently noticed, but not such as might have been expected from the red ink. It seems likely that the size of the capillaries was less than 10^{-5} cm. in diameter. It must be remembered that both capillary "suction" and the tendency of moisture to condense in a capillary tube, increase as the diameter of the tube decreases. In the case of capillary "suction," the effect is inversely proportional to the diameter. In the case of condensation the ratio of the saturation vapor pressure on a plane surface and in a capillary tube is given by the expression

$$\log_{10} \frac{\omega}{\omega'} = \frac{5.6 \times 10^{-8}}{r}$$

where ω is the saturation vapor pressure for the plane surface and ω' that for the capillary.

Taking this latter effect, it is well-known that for capillary tubes, where the radius is 10^{-5} cm. the saturation and vapor pressure on a plane and in such a capillary are very approximately the same, whereas for tubes of 10^{-7} cm. radius 30 per cent humidity on a plane surafce would be enough to cause saturation of such a tube.

It will therefore be seen that for the capillary tubes in insulators as we find them, the air is always practically saturated, and if tubes exist whose size is greater than 10^{-8} (the ordinary molecular size) and less than 10^{-6}, there will be a very strong tendency for moisture to condense, and it is this tendency, both owing to capillary "suction" and to condensation, which we consider has been the cause of the deterioration that has been experienced.

It cannot be too strongly emphasized that a porous insulator is certain sooner or later to give trouble. The pores of such an insulator consist of extremely fine capillary tubes, and the whole tendency of moisture, is to condense in such tubes, which never, even on the warmest day, a corresponding tendency for the moisture to evaporate. Thus the moisture is always increasing in quantity within the body of the insulator until a time comes when the insulator is electrically so much weakened by the accumulated moisture, that it punctures and serious trouble results. The authors consider that no laboratory test for porosity, however severe, can be as drastic as prolonged exposure to the atmospheric conditions in all weathers. Any batch of insulators showing porosity should be rejected unhesitatingly, or trouble is certain in the long run.

The observations made in the fog area referred to are interesting. The area extends from Christchurch, westward for a distance of 16 miles, and is no doubt due to the prevalent easterly winds blowing in from the sea, carrying westward the smoke particles of Christchurch, and moisture laden air from the sea. It is on these smoke particles that the moisture condenses and forms the mist in the region referred to. Further out than 16 miles the effect is not so perceptible. See Fig. 4.

TABLE I.—INSULATOR REPLACEMENTS

Per Area—Per Month

Year		Jan.			Feb.			Mar.			Apr.			May			June			July			Aug.			Sept.			Oct.			Nov.			Dec.			Total per area		Total per year
		N	S	F	N	S	F	N	S	F	N	S	F	N	S	F	N	S	F	N	S	F	N	S	F	N	S	F	N	S	F	N	S	F	N	S	F			
1915	Fog	..	..	..	..	..	..	..	..	..	..	..	0	..	2	2	1	1	2	..	..	0	..	..	0	..	1	1	..	1	1	3	..	3	3	2	5	Fog	14	26
	Non Fog	..	..	..	..	..	..	..	..	..	3	..	3	..	1	1	1	1	2	..	..	0	..	..	0	..	3	3	1	1	2	..	..	0	1	..	1	Non Fog	12	
1916	Fog	1	4	5	4	..	4	..	..	0	2	..	2	..	..	0	..	..	0	3	1	4	..	..	0	..	..	0	..	..	0	..	..	0	3	1	4	Fog	19	33
	Non Fog	2	5	7	..	..	0	..	..	0	2	..	2	..	..	0	..	..	0	..	..	0	1	..	1	..	..	0	..	..	0	..	..	0	..	4	4	Non Fog	14	
1917	Fog	1	..	1	1	11	12	..	1	1	1	1	2	3	1	4	1	..	1	..	..	0	..	2	2	2	..	2	..	3	3	..	..	0	..	2	2	Fog	30	57
	Non Fog	1	..	1	2	1	3	..	1	1	2	1	3	2	5	7	1	2	3	..	..	0	1	1	2	3	..	3	..	3	3	..	..	0	..	1	1	Non Fog	27	
1918	Fog	1	..	1	..	4	4	2	..	2	..	..	0	2	2	4	..	2	2	3	4	7	2	1	3	2	..	2	5	1	6	2	2	4	..	5	5	Fog	40	78
	Non Fog	1	..	1	..	3	3	..	..	0	..	..	0	1	1	2	..	2	2	2	5	7	..	2	2	2	..	2	6	3	9	3	2	5	..	5	5	Non Fog	38	
1919	Fog	..	..	0	6	..	6	..	4	4	..	..	0	..	2	2	6	..	6	1	4	5	2	..	2	2	2	4	..	3	3	..	..	0	2	2	4	Fog	36	62
	Non Fog	1	..	1	4	..	4	..	2	2	..	..	0	..	..	0	..	..	0	1	3	4	..	2	2	1	2	3	2	..	2	5	..	5	..	3	3	Non Fog	26	
1920	Fog	1	..	1	3	13	16	10	3	13	..	1	1	8	1	9	17	6	23	..	..	0	..	..	0	..	7	7	..	..	0	6	..	6	4	16	20	Fog	96	121
	Non Fog	1	..	1	..	2	2	2	..	2	..	3	3	..	..	0	7	..	7	..	..	0	..	..	0	..	2	2	..	..	0	1	..	1	1	6	7	Non Fog	25	
1921	Fog	2	6	8	14	3	17	2	..	2	..	..	0	4	3	7	..	..	0	8	5	13	3	3	6	7	..	7	3	..	3	..	4	4	..	..	..	Fog		
	Non Fog	1	1	2	1	..	1	1	..	1	..	..	0	..	..	0	..	..	0	2	1	3	..	1	1	..	..	0	..	..	0	..	..	0	..	..	..	Non Fog		

Fog Area 16 miles. Non-Fog Area 46 miles.

The two 66,000-volt transmission lines referred to were erected in 1914 and have been in continuous service since 1915, and Table I shows the number of pin insulators which have failed in the consecutive years of service.

This table is plotted in Fig. 4, and Fig. 5 shows the total replacements.

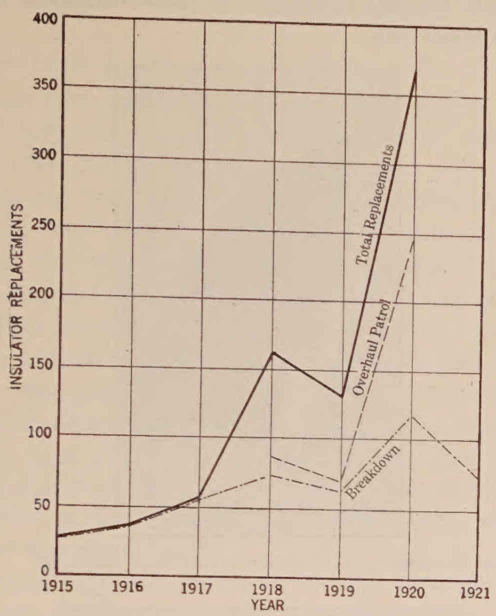

FIG. 5—CURVES SHOWING INSULATOR REPLACEMENTS

In addition to these, 72 suspension disks (12 strings of 6 each) used at anchor towers, were replaced as a result of the complete failing of two strings (12 disks).

Dealing first with the pin type, it will be seen for the year 1919-1920 that over 360 were replaced due to all causes and 100 of these were selected at random and tested on the high-frequency oscillator.

58 were found to be "down" on 2 or more shells.

42 were found damaged on top shell only. It will therefore be seen that not even one per cent was electrically whole.

36 of the suspension type were tested and 22 or 60 per cent were found to be "down" and a test under hydrostatic pressure showed the porcelain to be of a porous nature.

TESTS AND RESULTS—PIN-TYPE INSULATORS

The following is a summary of the average results of many tests on insulators by various makers.

Tables of Dry Flash-over Pressures in Kilovolts (high frequency) 4-Shell and 3-Shell Pin Type

Maker	Shell No. 1	Shell No. 2	Shell No. 3	Shell No. 4
A.	74 Kv.	55 Kv.	66 Kv.	75 Kv.
B.	66 "	65 "	76 "	60 "
C.	70 "	50 "	66 "	64 "
D.	76 "	68 "	92 "	
E.	72 "	74 "	66 "	
A.1	82 "	56 "	70 "	
A.2	64 "	64 "	80 "	
F.	64 "	67 "	66 "	
E.1	58 "	74 "	58 "	
E.2	60 "	50 "	64 "	
E.3	45 "	33 "	45 "	
G.	65 "	55 "	..	

Maker A—66,000-Volt 4-Shell Pin Type. This insulator which had not been in service, was, after testing all right on each shell at both high and low frequency, subjected to hydrostatic pressure test of 246,000 lb-hr. with an average of 1440 lb. per sq. in.

After immersion, a repetition of the electrical tests showed the insulator to be as good electrically as it was before immersion, and when broken up, not the slightest sign of penetration could be seen.

Maker B—66,000-Volt 4-Shell Pin Type. This insulator had been in service since 1914, but had been removed 5 years later owing to having shown signs of puncture on one shell on overhaul.

Electrical test showed the shells to be in the following condition:

	Shell 1	Shell 2	Shell 3	Shell 4
Before Immersion.	O. K.	O. K.	Punctured	O. K.
After Immersion...	O. K.	Conducting	Punctured	O. K.

It will be noted that No. 2 shell failed under the hydrostatic pressure test, which consisted of 280,000 pound-hours.

After leaving the porosity vessel and undergoing the after-immersion electrical tests, the insulator was broken up and examined for penetration of the dye. Color was seen in the crown of the first shell, but the penetration was apparently insufficient to cause the shell to fail on the electrical test. The discoloration

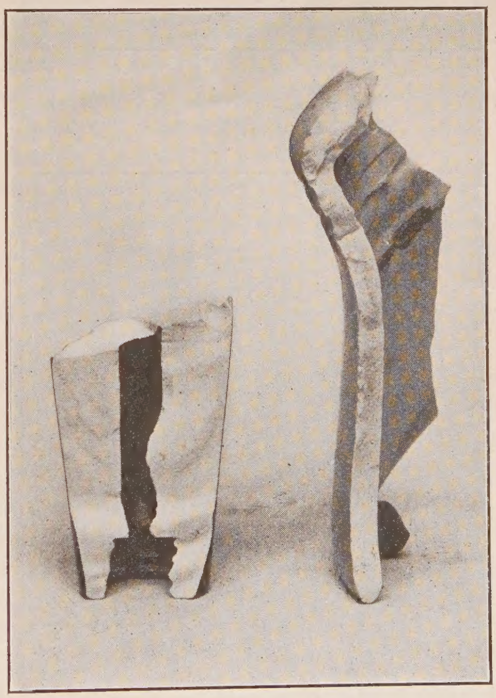

FIG. 6—SHOWING ON RIGHT PENETRATION IN SECOND SHELL, AND ON LEFT, GOOD PORCELAIN WHICH HAS BEEN SUBJECTED TO SAME TESTS

of the second shell was most marked. It would seem as if the dye had found its way into the shell through the glazing, and as seen above, the tests showed the shell to be practically a conductor after the porosity test.

In the third shell, the only sign of penetration was found just around the small hole in the shell where puncture had taken place prior to immersion and was evidently the cause of the puncture.

In the fourth shell, the porcelain was white and satisfactory throughout. It seems reasonable to assume this insulator was sound as far as the factory tests could reveal when first put on the line, but had gradually deteriorated, owing to the material being initially porous. Fig. 6 shows the penetration in a section of shell No. 2 mentioned above.

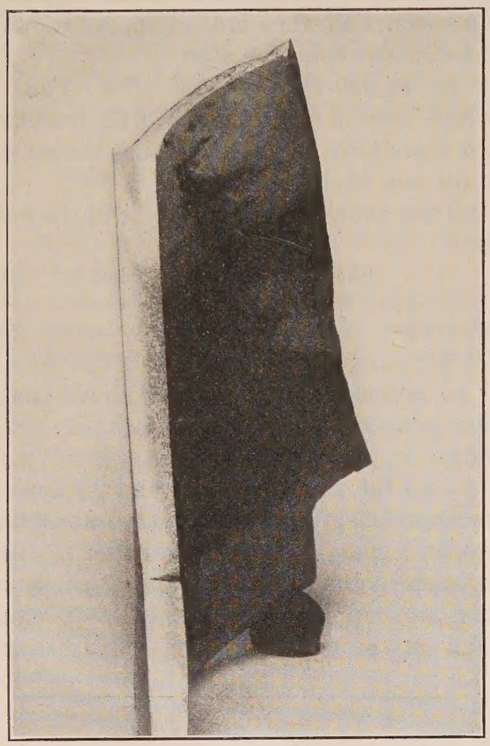

Fig. 7—Showing Piece Selected at Random from Whole Insulators

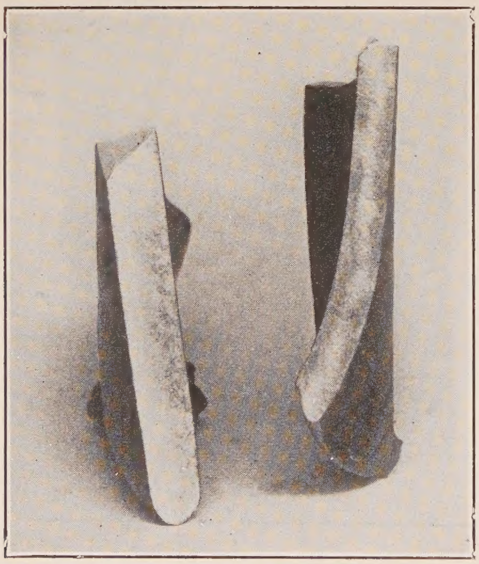

Fig. 7a

Another insulator of the same type, by the same maker, had been on the line a year longer than the previous one, and was removed owing to a mechanical fracture having been observed, probably due to rifle fire or other external cause. Pieces of this insulator were subjected to a hydrostatic pressure of 280,000 lb-hours, after which, when broken into very small pieces, not the slightest sign of penetration of the dye could be observed.

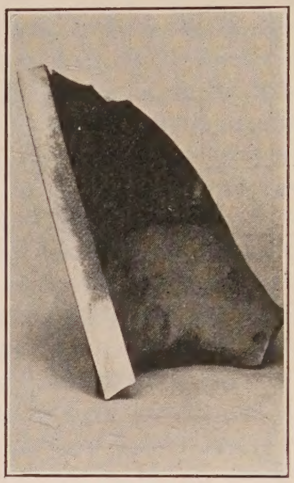

Fig. 8—Showing Piece of the Bad Shells

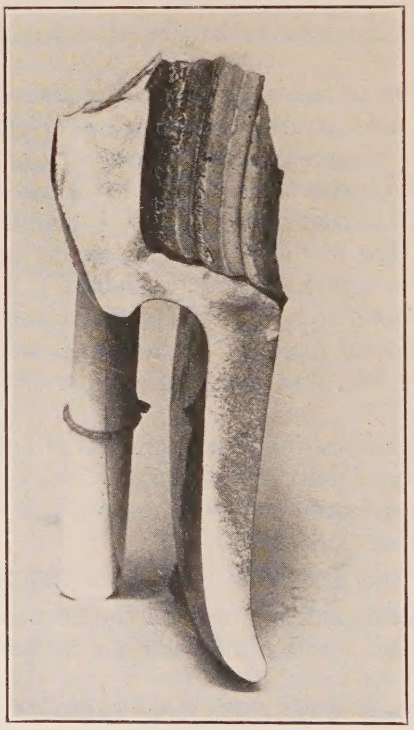

Fig. 8a—Showing Piece of the Top Shell

It is therefore reasonable to assume, that apart from the mechanical fracture, the insulator was electrically as good as when first put on the line and would have remained so indefinitely, had it not been replaced.

Another insulator of the same type and maker (B) was immersed in water at atmospheric pressure for four years.

The electrical tests made in 1917 before immersion,

showed the insulator to be good after flashover for one minute on each shell, at both high and low frequency.

After leaving the tub, in 1921, the insulator was wiped and allowed to dry for one hour in the ordinary atmosphere after which it was, where possible, taken up to flashover on high frequency, with the following results:

Shell 1	Shell 2	Shell 3	Shell 4
Punctured under 50,000 volts.	O. K.	O. K.	O ·K.

It was then subjected to the hydrostatic pressure test of 290,000 lb-hours, after which it was again tested, with the same electrical results.

On being broken up, no sign of penetration was visible in Shell No. 1. This was probably due to the fact that four years immersion had saturated the shell, and no more water (colored) could be forced in.

Another insulator, by the same maker (B) which had been in service over six years and which had failed in service was subjected to hydrostatic pressure test of 280,000 lb-hours and when broken up after leaving the porosity vessel the penetration was extremely marked throughout every part of the whole four shells, it was impossible to find even a most minute part, where the dye had not penetrated.

It seems only reasonable to assume, that this insulator let the line down; not due to surge or the like, but simply that it had become impregnated with moisture, through being porous, and had therefore eventually become practically a conductor for extra-high-tension pressure (Figs. 7 and 7A).

Still another 66,000-volt pin-type insulator by Maker B, which had been in service for six years, and failed from no apparent cause, was subjected to the hydrostatic pressure test of 280,000 lb-hours and when taken out of the porosity vessel and broken up, it was found that whereas two of the shells were the same as the last mentioned, *i. e.*, penetrated right through, the other 2 shells were of quite good material.

There seems no doubt that this breakdown was caused by the power arc tending to flash over the insulator, that the two shells were practically conductors, and therefore ruptured by being in the direct path of the arc, thus causing the complete wreck of the other shells.

The individual testing of each shell as urged in this paper, would have obviated this trouble. (Figs. 8 and 8A.)

Maker C—66,000-Volt 4-Shell Pin Type withstood all electrical tests and showed no sign of penetration after having been through the hydrostatic pressure test.

Maker E—66,000-Volt 4-Shell Pin Type. A firm which specializes in the manufacture of E. H. T. insulators, sent a special sample insulator which was expected to withstand any electrical tests applied, having withstood all the maker's tests.

Each shell was tested separately up to flashover on 50 cycle pressure, which each shell withstood.

Each shell was then tested on the high-frequency oscillator, shells 1 and 2 withstood flashover satisfactorily, but No. 3 punctured decisively in the thickest part, under 40,000 volts.

The puncture path was quite perceptible when the shell was broken up, and had the appearance of a seam of flint, which apparently had not been "found" by the low frequency test.

If such results are obtained with a specially selected sample, what risk has an undertaking in accepting many thousands which have been passed by the maker, due to perhaps less than 10 per cent of their number having passed a mild low-frequency test?

In fairness to the maker, it should be mentioned that all his tests were made on 25-cycle pressure and the whole insulator, after being subjected to the hydrostatic pressure test, showed absolutely no signs of penetration.

Maker F. Another case of a world-known porcelain firm but not insulator makers, who desired to enter the electrical field, submitted a three-shell 66,000-volt pin type insulator for test. This insulator was guaranteed tested, by certified authorities, to 125,000 volts head to pin.

Each shell was taken up to flashover on 50-cycle pressure, which it withstood for two or three seconds, but on the high-frequency pressure, one shell only stood up to flashover, while the remaining two failed decisively under 30,000 and 40,000 respectively.

The insulator was then subjected to the hydrostatic pressure test. The number of pound-hours submersion was 300,000 and the insulator was tested after immersion and showed the first shell to be satisfactory in so far as flashover was concerned. The application of high pressure completely wrecked the other two shells, and when broken up, signs of penetration of the dye were quite obvious in all shells. It is reasonable to assume, that had the hydrostatic pressure been kept on for a longer period the dye would have been forced right through, sufficiently to form a path electrically through the first shell.

This again demonstrates the necessity for individual shell testing, because this insulator had been tested by authorities as good for 125,000 volts. This was true, because even after the insulator had been under the hydrostatic pressure test, it would withstand 120,000 volts from head to pin. But should such an insulator be put on a line? And yet how many, in such a condition are unwittingly put on a line?

Maker D. A particularly good insulator by this maker, although it has only three shells, has nearly as high flashover as some of the four-shell type.

It withstood all electrical tests satisfactorily and was then subjected to the hydrostatic pressure test, after which it also withstood the repetition electrical tests. It was further given Creighton's super-spark potential tests on each shell for five minutes, and withstood this test. On breaking up, not the slightest sign of penetration could be seen; and if the maker could only guarantee consistency, this insulator, by

virtue of its shape (Fig. 13) and quality of material, should make many friends, but as seen from the foregoing tests, purchasing engineers have reason to be suspicious, unless some guarantee is given that each and every shell of each insulator has been subjected to such tests as those described.

Tests and Results 66,000-Volt Suspension Insulators

66,000-Volt Suspension Type	
Maker	Flash-Over kv.
H.	110.
H.1	98.
B.1	88.
B.2	80.
A.3	80. Approx.

In addition to the several types of pin insulators tested, three makes and five samples of different shapes of suspension insulators were included in the investigations, and the results have been that three samples or 60 per cent failed to withstand the prescribed tests satisfactorily; the two that did withstand the tests coming from one Maker H who has undoubtedly specialized in this type and succeeded in attaining something unassailable in his product.

The flashover pressures are given below, and it will be noted that apparently makers have opposite aims; Maker H having, in his latest product, increased his leakage distance, while Maker B in his latest product, has decreased his leakage distances as shown:

Maker H.	received in	1917	has	flashover	of	98,000	volts
" H.	"	" 1921	"	"	"	110,000	"
" B.1	"	" 1914	"	"	"	88,000	"
" B.2	"	" 1921	"	"	"	80,000	"

The product of Maker H has successfully withstood all tests, while that of Maker B has failed badly in both samples.

Maker A, who has a reputation for pin insulators, equal to the best known, had failed up to that time in his attempt to produce a suspension insulator. There is an inherent weakness in the design, in that the insulator punctures much below flashover pressure, also the porcelain was found to be unmistakably porous, illustrating the fact that even the best of porcelain makers are inconsistent in their products in the case of new types or shapes.

Maker B. (*1*). This supension insulator supplied in 1913 had been in service over six years, being one of a string of six which failed completely in service, from no apparent cause, just prior to the day load coming on. It was subjected to the hydrostatic pressure test, and on breaking up, after leaving the porosity vessel, it was found that the dye had penetrated to a considerable depth. (Figs. 9 and 9A.) From the above it can be reasonably assumed that the failure of this and the rest of the string of disks from which it came, was due to deterioration caused by the material being initially porous and moisture had gradually accumulated, until the material lost its insulating properties.

Maker B. (*2*). This was a new type supplied recently by the same maker who was seeking to redeem his reputation, which was seriously jeopardized, by results obtained from his earlier insulators. The sample withstood all electrical tests, both before and after having been subjected to the hydrostatic pressure test, and when broken up, no signs of penetration of the dye were observed, but a second sample, when tested dry, punctured decisively at 75,000 volts at 50 cycles.

The two pieces of the broken second sample were subjected to the hydrostatic pressure test, and on breaking up after leaving the porosity vessel, it was found that the dye had penetrated deeply at the weakest and most critical point of the insulator. This was

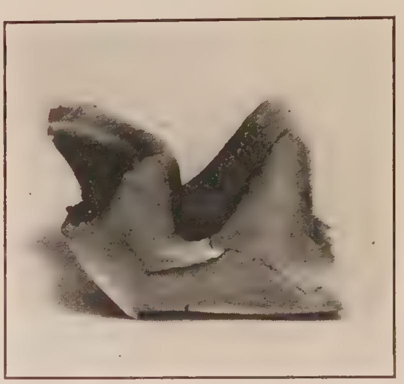

Fig. 9—Piece of Suspension Insulator Showing Marked Penetration. Maker B's Early Product

Fig. 9a

regrettable with such a recent production (1921), but certainly goes to confirm the author's contention regarding individual tests (Figs. 10 and 10a.)

Maker A. (*3*). *66,000-Volt Strain Insulator.* This insulator apparently has an inherent weakness in its design, inasmuch as several samples, punctured decisively under 60,000 volts (flashover should be about 80,000 volts).

One of the unbroken samples was subjected to the hydrostatic pressure test, and when broken up, after leaving the porosity vessel, it was found that the dye had penetrated throughout the whole thickness, in fact,

this was amongst the worst material handled in these investigations, although as before stated, this maker's material in the pin type productions, is unassailable and equal to the best handled by the authors.

Maker H. 66,000-Volt Suspension Insulator. This maker claims to have produced a porcelain that is unassailable in that it is perfectly vitrified and will

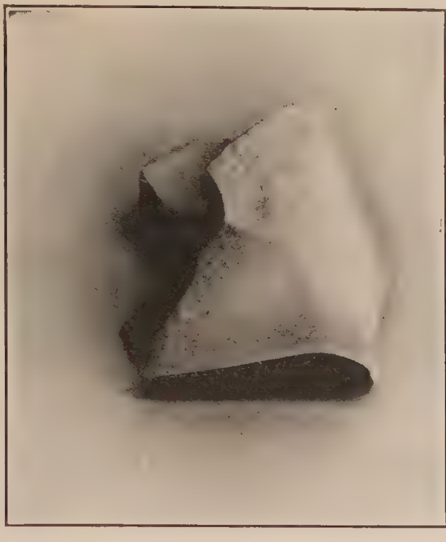

FIG. 10—SHOWING MAKER B'S LATER PRODUCT IN SUSPENSION TYPE

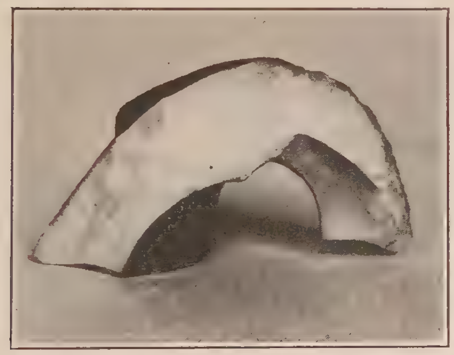

FIG. 10A

withstand any electrical, mechanical or porosity tests. The insulator was subjected rigidly to the whole of the tests mentioned herein, and after the porosity tests, was further given Creighton's super-spark potential tests for five minutes. On breaking up, after having successfully stood all tests, not the slightest sign of penetration of the dye could be seen.

It is this type of insulator that is mentioned under Tests with High Frequency Oscillators, and goes to show that insulators can be made that will successfully withstand the tests shown, and there seems no reason why such insulators should not remain good in service for an indefinite period.

Maker E. Sample (3). 33,000-Volt Pin Type Insulator. This insulator successfully withstood all electrical tests both before and after having been subjected to the hydrostatic pressure tests, and when broken up, not the slightest sign of penetration of the dye could be seen; and the material was of a particularly good satin-like appearance.

Maker G. 33,000-Volt Pin Type Insulator. This also withstood all electrical tests, successfully, both before and after having been subjected to the hydrostatic pressure tests. When broken up, not the slightest sign of penetration could be seen, and this ranks as the finest sample of electrical porcelain seen by the authors.

11,000 VOLT PIN TYPE INSULATORS

The testing of these insulators is regarded as particularly important, because they are within the range of local New Zealand manufacture, and the difficulty and cost of obtaining imported insulators during the war made it important that local insulators should be developed if possible. Investigations were made on those of two New Zealand makers (I and L) one Australian (K) and one American (E).

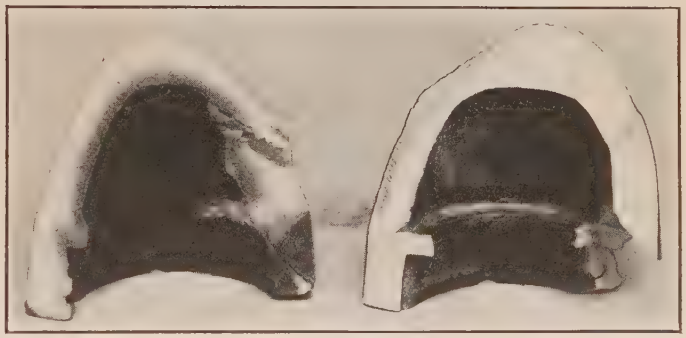

FIG. 11—SHOWING LOCAL PRODUCTS, ON LEFT BY MAKER K (BAD) AND ON RIGHT BY MAKER I (GOOD)

FIG. 11A—LOCAL PRODUCT BY MAKER K. (VERY BAD)

Maker E. Sample 4. This insulator punctured just below flashover during acceptance test, and was subjected to hydrostatic pressure test. Under this it showed distinct signs of penetration through the glaze, and particularly to a depth of about ¼ inch on each side of the puncture path, which was through the thickest part of the insulator, well down from the neck. Evi-

dently there was a porous seam existing where the insulator broke down. Three other samples failed in the same way out of thirty selected at random from a shipment of 30,000, indicating a very high proportion of defective porcelain.

Maker K. A special batch of insulators by this maker failed to withstand even working pressure, and a few were subjected to the hydrostatic pressure test.

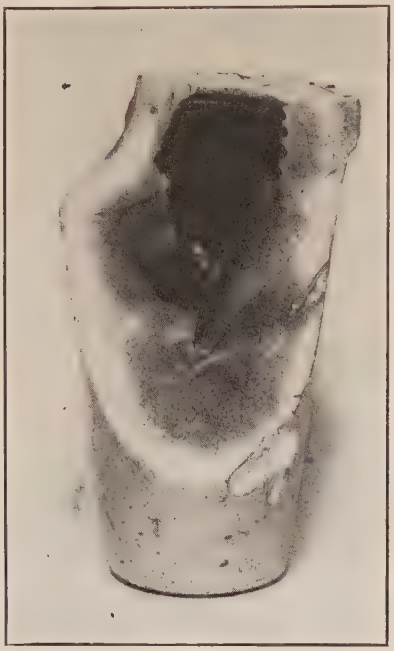

FIG. 11B—LOCAL PRODUCT BUS-BAR PILLAR (VERY BAD)

FIG. 11C—LOCAL PRODUCT (VERY BAD)

Figs. 11, 11A, 11B and 11C show broken samples after leaving the porosity vessel. It will be seen that the dye had penetrated deeply through the entire body, hence their puncture at such a low pressure. Apparently in this case no effective factory test whatever could have been employed.

New Zealand Manufacturers. The insulator by Maker I withstood all electrical tests successfully, both before and after being subjected to hydrostatic pressure test, and when broken up showed no sign of penetration. Later insulators have given equally good results, and the quality of the porcelain has apparently improved, indicating that local manufacture of this type of insulator is quite successful.

Another maker "L", after several attempts produced a very good insulator for use on low-tension work up to 500-volts, but for high-tension work failed distinctly, all his porcelain being porous.

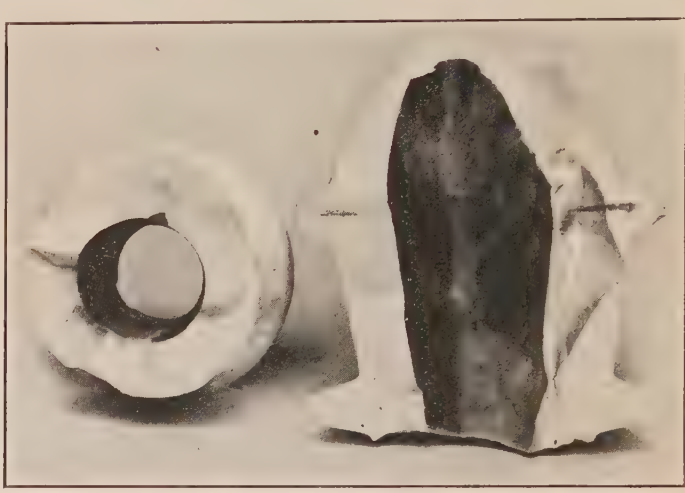

FIG. 12—MAKER M. SHOWING MARKED PENETRATION IN APPARENTLY A SEAM OF POROUS MATERIAL ON RIGHT AND A DEPTH OF ABOUT ¼ INCH FROM INSIDE EDGE ON LEFT

FIG. 12A—SHOWING SAMPLE OF HEAVILY GLAZED INSULATOR INTO WHICH THE DYE HAS BEEN FORCED THROUGHOUT THE ENTIRE MASS

Extra-High-Tension Bushing. A bushing for 66,000-volt circuits was supplied by Maker M—manufactured in England—who was seeking to enter the electrical field. It is assumed that the insulator was given some kind of test before being sent out such a distance, but on being tested electrically dry as received it punctured decisively in the thickest part, on approaching 40,000 volts. On being subjected to hydrostatic pressure test distinct signs of penetration were obvious, the dye being forced through the glazing to a depth of nearly

1/4 inch, and in the thickest part there was a distinct porous band, which had been apparently moulded with the insulator. Needless to say no further insulators were purchased from a manufacturer allowing such work to be exported. (Figs. 12 and 12A.)

Shape of Insulators. The shape of high-tension pin insulators has undergone a radical change since 1917, mainly on the lines suggested by Gilchrist and Kline Felter (*Electric Journal,* Vol. 15, No. 11, page 445). The original type adopted in the Lake Coleridge system, Fig. 13, manufactured by Maker B did not give good results owing to the shells practically enveloping each other so that it was impossible for the weather or wind to clean the inner shells, thus lowering the factor of safety of the insulator. In later designs the shells are more open so that not only is the weather able to displace such deposits, but the planes between the shells follow more closely the equipotential surfaces, and the body of the insulator conforms to the lines of electrostatic field as suggested by Gilchrist and Kline Felter.

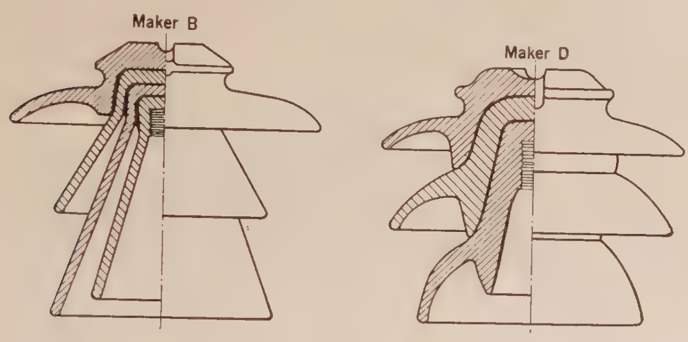

Fig. 13

This improved shape, coupled with the real improvement and greater consistency in quality of the porcelain has effected a substantial improvement in the life of the high tension insulators.

Glazing. Our experiments showed that glazing, even when over the entire shell of the insulator is no protection against impregnation by moisture. In the early stages of insulator manufacture apparently some importance was attached to the insulating quality of the glaze, and experience of puncture tests either in oil or in air tend to confirm this, in that when approximately the puncture value is reached, there is a definite time lag before the glaze starts to crack or craze, but when it does so, complete puncture quickly follows. Apparently then, the glaze has some value as a dielectric, but when once it breaks down it is no further protection, and when crazed, it is of course easily penetrated by moisture. Several of the figures herewith show penetration all along the glazed edges, indicating that the moisture must have entered through the glazed surface. We consider that our experiments demonstrate that glazing is no protection against the penetration of moisture, and that the insulator can be and should be made non-porous. Glaze should certainly not be put on to make good the defects of indifferent body material, and it will not do so.

General. The great importance of the transmission line insulator in the early construction days of most undertakings is usually lost sight of owing to the numerous urgent requirements of the rest of the plant, and as a rule, testing of insulators is left until trouble arises from breakdown on the transmission line. Extraordinary care is usually taken in testing the generators, water wheels, and other details, but the insulators are left to work out their own salvation, relying in some cases, quite without justification, on the makers' guarantees. The usual method is to dump the crates of insulators in the yard or alongside the poles, and leave them there exposed to the weather until they are ready for erection. During this period any porous insulators will certainly become more or less penetrated with moisture, and unless the factory tests are very thorough, trouble will ensue sooner or later. The authors consider that their observations indicate that there is need for much more co-operation between the manufacturer and the operating engineer with the object of reducing the maintenance. It is now general practise on the part of manufacturers to reduce as far as possible the stresses due to expansion and contraction and temperature variations, and with this object various types of jointing material have been introduced between the shells, which are intended to take the stresses due to temperature changes, thus reducing the cracking of shells due to such stresses.

Annual Overhaul. Annual overhaul on the transmission line is also very essential for the detection of defects not perceptible from the ground. This work of course has to be done as expeditiously as possible and in the best weather.

Summary

From the tests and investigations described herein the following conclusions may be drawn:

1. That insulators for extra-high-tension work, before they are put into service should be subjected individually in the case of suspension units and on each shell in the case of pin insulators, to flash-over pressure for a definite period at both high and low frequency, or at least at high frequency, either by the maker, or preferably by the purchaser after delivery, when the maker should be prepared to bear the cost of rejected ones.

2. That a percentage of each shipment of insulators should be subjected to a hydrostatic pressure test at least as severe as that described herein. One manufacturer describes his competitor's specification for porosity as "a joke," and proposes instead a porosity test of 4800 lb-hours; which appears to the authors to be equally a joke.

3. That insulators can be made and are being made that will not be overstressed by such tests, and which should remain good in service for an indefinite period.

4. That a proportion of insulators supplied hitherto have been porous, and should be replaced at once by insulators that have been thoroughly tested.

5. Extreme care should be exercised in the selection

of the type and shape of insulator, having regard to the form of electrostatic field and to the self-cleansing form of the insulator.

6. There is room for more co-operation between the maker and the user in the matter of handling and maintaining insulator service.

7. That in a country such as New Zealand where it is proposed to develop hydroelectric power to the utmost limit of its resources, a public testing laboratory should be established, where various undertakings could arrange for tests herein described, thus giving them a guarantee that the material received would be of the best quality, and eliminate the annoyance and mistrust engendered in the public mind by insulator breakdowns.

We desire to express our most cordial thanks to Mr. L. Birks the Chief Electrical Engineer for the Dominion, for the support and help he has given us in this work. Much of the information contained in the paper is Departmental, and for permission to publish this we are indebted to him.

Our thanks are also due to The New Zealand Institute which gave us the monetary grant which enabled the porosity tests described to be developed.

Conservation or Waste of Material in Educational Institutions

BY J. W. UPP
Member, A. I. E. E.
General Electric Company, Schenectady, N. Y.

THE successful operation of a republican form of government depends in large measure upon an educated people. It is obviously impossible to let the people rule unless their intellectual training has reached the point where they can distinguish between what is right and what is wrong. The better they are educated, the more likelihood there is that the governmental agencies will function in a proper manner.

These facts have been clearly recognized in this country ever since the present form of government was established with the result that our educational institutions have always received the active interest and support of an intelligent and generous people. We have pointed with pride to the country schools in which so many of our greatest men received their early educational training and have always given to such schools much of the credit for the successes achieved by those who attended them.

In other words, the American people have always believed so thoroughly in scholastic training that it was natural for them to exalt this work and to furnish funds for its continuance.

The same applies equally to the college and university. Early in our history we set up institutions of higher learning to supplement the work of the common or public schools and these institutions have constantly grown in number, size and importance to the present day.

The point we are trying to make is that no one without good reason would find fault with a system we all believed in. We do not believe, however, in all the details of its present day administration and accomplishments. We are forced to conclude that although our system of education has an uncounted number of highly commendable features, it has also some faults which should be corrected.

In discussing the work of the educational institution as regards the conservation or waste of material, we shall compare its activities and results to those of a modern manufacturing establishment. We shall do this because it is a convenient method to illustrate the points we have in mind.

Is it fair to draw comparison between a modern manufacturer and a modern educational institution? To the writer it seems quite in order to do so. Modern business is conducted on a very high ethical plane and directed by men of education and ability who must meet the keenest competition and have their accomplishments measured by actual values. The most efficient management is the one which obtains the largest amount of high grade finished product at moderate cost from a given amount of raw material. Surely there can be no objection to applying this standard to measure our educational institutions.

In a successful manufacturing establishment, close attention is always given to the material which will enter into the finished product, and the most careful specifications are drawn to insure the material purchased being of a grade suitable for the article which is to be produced. And these specifications are always supplemented by rigid inspection of the material when it is received. When the material has been accepted, it is the obligation of the management to use it to advantage and through efficient direction to obtain the maximum

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number of finished articles. It is also the duty of the management to use to advantage all by-products, and to salvage the material which has been damaged in handling or through careless workmanship, or which may have been spoiled by workmen who are not properly instructed or supervised.

Do our educational institutions accept the responsibilities for output that they should accept? Do they give the same attention to conservation of material that is a necessity in ordinary business undertakings? To the writer, it does not appear that they do and it is the purpose of this paper to draw attention to what appears as a profitable point for consideration.

Our educational institutions are furnished with the finest grade of material that the world produces. This material is selected under rigid specifications. It is not accepted until it is found of the grade that is considered suitable for the product that is desired. It comes to the educational institutions under the very best conditions with the certainty of every assistance that can possibly be given to maintain the standard. Every young man who enters an educational institution comes with the unqualified backing of family and friends and the kind of backing that should be of the greatest value. What is done with this material after it is received? It is beyond understanding that in the first period of the freshman year it is found that the material which has been selected under such carefully prepared specifications is defective to so large a degree. It is equally disturbing to find there is further rejection in the succeeding periods of freshman, sophomore, junior and even senior years. Is the fault with the material? If so, there are serious faults in the specifications. Is the fault with the handling of the material? If so, the methods of handling are inefficient.

The writer in looking over the records of many of the highest grade educational institutions cannot find a single one which to a business man would be considered satisfactory. The results, if duplicated in a modern business, would be the cause for criticism and there would be certain failure.

Is the comparison unreasonable? Is it proper to ask that the college or university give a better accounting of the resources which are under its immediate direction?

Each year, we find very great attention being given to the size of the entering classes, also attention to the number of those who have received degrees and diplomas; but has there ever been a published statement at commencement as to the number who have failed to complete the work which they started four years earlier? How many of our instructors would be commended if they pointed to a class which had completed the course without a failure? How many of our professors would feel that they had properly conducted their work if they did pass every one in their classes? How many accept personal responsibility for the failure of any individual under their supervision who does not complete the prescribed work in a satisfactory manner?

The selection and training of the teacher is probably the most important phase of college administration. The teaching professions is justly recognized as of very great importance. It calls for leaders of the highest type. The mere ability to impart to the student the information contained in the text books is only one of the requirements. There must also be wise sympathetic and forceful leadership to direct the students' efforts or there will be much confusion, conflict and waste. On every staff and in every faculty there are many with all the fine characteristics that are required. Of these, we wish to voice our appreciation and to commend the success they have obtained in directing the students along paths which have been so productive. The teacher to be of maximum value must have a tremendously vital interest in his subject and in the great responsibility of his position. He should be of a type which appeals strongly to a vigorous, energetic young man, of a type which takes as much interest in student affairs as the student himself. How, otherwise, can he hold their interest and how, otherwise, can he make them believe that the things he teaches are worth while?

The teacher must be selected with great care and must then receive a sufficient salary to enable him to take his proper place in the community. He must be a successful man himself if he can ever be hoped to teach success to others. The difference between the successful and the unsuccessful teacher is certainly not determined entirely by the book knowledge each possesses. It depends largely on their comparative attributes for real leadership.

These leaders are necessary. How to obtain them, I leave for the college authorities to decide. That they do not exist in sufficient numbers at this time is evidenced by the results obtained.

One of the greatest wastes of human material in connection with our colleges results from the student following the wrong course. This is also one of the most difficult things to remedy.

The particular courses the students take depend to some extent upon the family's general desire to have them enter some certain profession. Very little detail or analytical study is given to the problem. The courses selected are usually determined by the relative popularity of some branch of engineering, law, medicine, etc., and have no relation whatever to the actual capabilities of the prospective students. The individual characteristics of the students, the type of training they have had in their homes, the ever changing needs of social, intellectual and industrial life, complicate the problem tremendously and make its attempted solution worthy of the deepest study.

The purpose of a college is to give an education to

those who enter its doors but of what that education should properly consist is surrounded by much hesitancy and doubt.

The subjects for study and the arrangement of the courses have always received considerable attention but there is still much to be done along this line. When it is necessary to force the sudents into studying subjects which they cannot see will be of advantage to them in later life, it is obviously very difficult to hold their interest. On the other hand, the students will give all the necessary time and intensive study to those things that interest him deeply. To create that interest is one of the most important duties that is met successfully by the real teacher. When the students fail, the teacher must take most of the blame.

It cannot be said that the educational institutions have not had the backing of the people, and that it is, therefore, difficult to obtain sufficient funds to pay for a sufficient number of teachers to give the students individual attention.

If the financial support received has been insufficient to meet the requirements, it is because of a weak presentation of the case. The people of this country will not knowingly let their educational institutions suffer if the matter is put before them in the proper light.

A college or university should be run according to the best modern business principles. That is, the administrators should be able to show a satisfactory return on the investment. The stockholders of any business corporation would soon withdraw their support if it should appear that the management was inefficient in carrying on its affairs; and the college or university will naturally receive the same treatment.

There is no doubt that even after the most careful selection, some of the material will be found defective, but can it not be used in some other manner? It will also be found that some of the material has been damaged in handling, but that too, can be usually repaired or used for some other equally valuable service. Some material too becomes defective because it has been handled by careless workmen or by workmen who have not been properly instructed and it is this material which it would appear should have the most attention.

That errors have been made in reference to this material which has been rejected as unsatisfactory, there can be no doubt. In the writer's experience, there have been many cases where not only has the damage been repaired, but later the material has been found of the most excellent grade, in some cases of such high grade that it required special attention in order that it might be most effectively used. It was rejected because its qualities were not understood, not because it was defective.

The modern manufacturer has a research department which devotes the entire time to finding ways of using to advantage materials which have heretofore been of little service, also to use materials where the results desired have not been obtained. Is there not a parallel work for educational institutions? Cannot a division of college work be made which would make it possible for a group of men connected with the faculty to study the causes of failure, to make the new applications, to revise the methods or change the work so that the ability of the individual could be properly developed and applied?

The writer has had an opportunity to observe young men and young women under various conditions,—those who have been marked as successful and those who have been marked as unsuccessful,—but in almost every case careful selection has given satisfactory results, and in practically every case it has been possible to encourage the individual to do what he set out to do and to accomplish the thing that was desired.

One of the most common causes of failure in the earlier years of educational work seems to be the improper direction of those who are immature. It would seem in order to apply more stringent regulations to those who are far from the years of discretion, and it certainly would be in order to do this if the results should prove that such regulations were warranted.

No doubt if the writer was actively engaged in directing the work of an educational institution, he would find the problems overwhelming. But as a business man, the solution of those problems would always be desired and sought for until the percentage of finished product was many degrees higher than it is in our educational institutions at this time. There is no desire to lower in any degree the very high standards which have been set. There is no desire to recommend that diplomas be given for work that has not been completed, but there is a firm belief that with different methods with more study given as to the causes of failure, it would be possible to effect a very considerable saving of material.

Is there a college or university today which is advertising the fact that anything short of 100 per cent output is viewed as a matter of concern, which has found the reasons for failure and is applying the remedies, which is holding itself up as a standard of excellence because its output is equal to its input?

We know of no such institution. We doubt if it exists. We doubt if it will ever exist, but we shall be satisfied that our colleges and universities are properly directed only when this condition is far more closely approximated than it is at the present time.

We wish to say again that there is not, nor can be, a more worthy purpose than the proper education of every young man and young woman, and everything should be done which can be of assistance in this direction.

Waste in every form should be eliminated.

Electrical Characteristics of Transmission Systems

BY HERBERT BRISTOL DWIGHT
Member, A. I. E. E.
Canadian Westinghouse Company, Ltd.

In making the electrical calculations for a long transmission line, it is desirable to include the effect of the step-up and step-down transformers and to make a direct calculation for the complete system, without any trial and error procedure. A method for doing this is described for constant-voltage lines, since long, high-power lines, especially those of 220,000 volts, usually require to be operated at constant voltage by means of synchronous condensers. The necessity of using the hyperbolic theory in calculating such lines is pointed out.

THE electrical characteristics of a simple transmission line of uniform design throughout are usually calculated from the resistance, reactance and capacitance of the line. However, the characteristics of the line alone are often not so useful to know as the characteristics of the complete system, including transformers and synchronous condensers, and sometimes with different types of conductors used on different parts of the line. Where synchronous condensers are used, it is usual to assume that they hold the voltage constant at certain points.

In this article is shown a method of calculating the characteristics of a constant-voltage transmission system, including the effect of the transformers, the distributed capacitance of the line, and changes in size and grouping of conductors.

It may be stated as a well-established fact that any transmission line long enough, and with a power load large enough to justify the adoption of 220,000 volts, will require to be operated as a constant-voltage transmission line, using synchronous condensers.

The adoption of 220,000 volts means increased cost of transformers, circuit breakers, line insulators, and towers which must be large enough to provide wide spacing between conductors. It will therefore, be economical to use such a high voltage only for a large block of power transmitted a long distance, and this is found to require a low resistance conductor of large size, approximating one inch in diameter. This large size of conductor is required also in order to avoid trouble from corona, though a large diameter for this purpose may be secured by the expedient of using a large steel core. Now, overhead conductors of very large size have several times as much reactance as resistance, so that the maximum load which may be carried by the line is determined by voltage variation and not by line loss. It is in such cases that synchronous condensers for holding the line voltage constant have been found to be most profitable.

It may also be stated that for any 220,000-volt transmission system, and, indeed, for much less important systems, it is necessary to take accurate account of the distributed capacitance according to the hyperbolic theory, in order to avoid serious errors in the calculated results.

This is very well shown by the transmission line problem given in Fig. 5 of F. G. Baum's paper on "Voltage Regulation and Insulation," JOURNAL of the A. I. E. E., August, 1921, page 648. Mr. Baum used an approximate method of calculation which was not based on the hyperbolic theory. As a result, he obtained a value of 124,000 kv-a. of synchronous condensers for a load of 104,000 kw. As a matter of fact, 82,000 kv-a. of synchronous condensers are required for the line in question at full load, which is the only condition considered in Mr. Baum's paper. Considering both no-load and full-load conditions, the required capacity to maintain constant voltage is 244,000 kv-a., or 235 per cent of the value of the load in kilowatts. There is also a considerable discrepancy in the calculated efficiency due to using the approximate method of calculation. The approximate method gives 71 per cent efficiency, but this should be 77 per cent, according to the data given.

It is doubtless true that synchronous condensers would be required at intervals in order to transmit power 800 miles at 220,000 volts, though possibly not at such close intervals as 150 miles. However, it is necessary to use the hyperbolic theory if even a rough estimate is to be made of the operation of the system or the amount of synchronous condensers required.

A very useful method of determining the size of conductor and the features of loading and controlling a constant-voltage transmission line, is to draw a circle diagram for the line in question. This shows the operation of the synchronous condensers under all conditions of load and it gives the maximum load which can be carried by the line at the voltages considered. The efficiency of transmission and power factor at the generators for various loads may also be conveniently plotted above the diagram. (See Fig. 2.)

The circle diagram is advantageous, first, because it gives results for all loads and not for one or two particular loads only. Second, because it is not a trial and error method but it gives results at once for the definite supply and receiver voltages chosen. In the third place, concentric circles may be drawn with practically no extra calculation whatever, to show the results for different values of the supply voltage E_s. (See Fig. 2.) In the fourth place, it is possible with very little extra work to obtain precise calculated results by means of the calculated data used in making the diagram.

The method of drawing a circle diagram of a constant-voltage transmission line, not including the step-up and step-down transformers, but taking account of the

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distributed capacity according to the hyperbolic theory, has been published by the author in "Constant-Voltage Transmission," pages 78 and 99. The present article gives formulas for drawing the diagram or calculating the results when the transformer resistances and reactances are included in the circuit, the notation used being similar to that in the book referred to. Average values have been taken for the transformer core loss and magnetizing current, and for the condenser loss, and these have been included in the calculation.

A similar method for including the transformer characteristics in the transmission circuit calculation has been worked up by Messrs. R. D. Evans and H. K. Sels and published by them in the *Electric Journal.* A useful reference in connection with this kind of calculation is 'The Calculation of Transmission Line Networks" by Prof. T. R. Rosebrugh, Bulletin No. 1. 1919, of the School of Engineering Research, University of Toronto, which gives the general circuit constants for several lines in parallel, in series-parallel, and with intermediate loads, etc. Such general constants are often applicable in the following circle diagram calculation.

By making allowance for the transformer characteristics, the preliminary calculation is made somewhat longer than for the line alone, but the construction of the diagram itself is not made any more complicated in any way.

Let the constant voltage at the low-tension side of the receiving transformers be E volts to neutral, (equivalent high-tension voltage). See Fig. 1. Let the load current combined with the reactive current from the synchronous condensers be $P + j\,Q$ amperes per conductor, (equivalent high-tension current). Q is a positive quantity when leading and negative when lagging. Let the average loss in the synchronous condensers be represented by the current P_c, in phase with E. Let the core loss and magnetizing current of the receiving transformers be represented by the admittance $G_{tr} + j\,B_{tr}$ at the average operating high-tension voltage. Let the corresponding quantity for the supply transformers be $G_{ts} + j\,B_{ts}$. The core loss current and the magnetizing current of a given transformer are assumed to flow in the primary winding of that transformer and not in the secondary winding. The impedance of the receiving transformers is $R_{tr} + j\,X_{tr}$, and that of the supply transformers is $R_{ts} + j\,X_{ts}$.

The process of calculating the data for the circle diagram consists in starting at the load end, where the voltage E and all other conditions are known except the current $P + j\,Q$. The voltage and current at each part of the system are then calculated, using numerical values of all quantities except that the letters $P + j\,Q$ will always appear. Thus finally the value of E_s will be obtained in terms of P and Q and numerical quantities, See Equation (**16**) and example I.

In Fig. 1 is indicated a typical constant-voltage transmission line. If the size of conductor, or the spacing, changes at a certain point on the line, the voltage E_{b1} at that point should be marked on the diagram and calculated in the usual way. Voltages in the calculation are considered measured to neutral, and currents are in amperes per conductor. The system is considered to be three-phase.

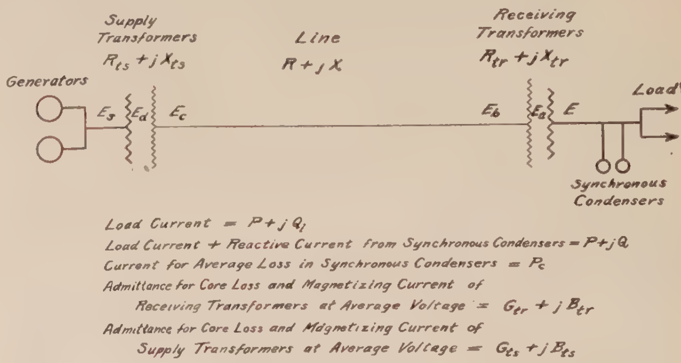

FIG. 1—SCHEME OF CONNECTIONS OF CONSTANT-VOLTAGE TRANSMISSION LINE

Numerical values, except for P and Q, are to be inserted in the following equations;

Current in secondary of receiving transformers

$$I_a = P + j\,Q + P_c \qquad \text{amperes per conductor} \quad (\mathbf{1})$$

Voltage induced in receiving transformers

$$E_a = E + 1/2\, I_a\, (R_{tr} + j\, X_{tr}) \qquad \text{volts to neutral} \quad (\mathbf{2})$$

Current in primary of receiving transformers

$$I_b = I_a + E_a\,(G_{tr} + j\,B_{tr}) \qquad \text{amperes per conductor} \quad (\mathbf{3})$$

Voltage at receiving end of transmission line

$$E_b = E_a + 1/2\, I_b\, (R_{tr} + j\, X_{tr}) \qquad \text{volts to neutral} \quad (\mathbf{4})$$

Voltage at supply end of transmission line

$$E_c = E_b\left(1 + \frac{Y\,Z}{2} + \frac{Y^2\,Z^2}{2 \times 3 \times 4} + \ldots\right) + I_b\, Z\left(1 + \frac{Y\,Z}{2 \times 3} + \frac{Y^2\,Z^2}{2 \times 3 \times 4 \times 5} + \ldots\right) \qquad \text{volts to neutral} \quad (\mathbf{5})$$

Current at supply end of transmission line

$$I_c = I_b\left(1 + \frac{Y\,Z}{2} + \frac{Y^2\,Z^2}{2 \times 3 \times 4} + \ldots\right) + E_b\, Y\left(1 + \frac{Y\,Z}{2 \times 3} + \frac{Y^2\,Z^2}{2 \times 3 \times 4 \times 5} + \ldots\right) \qquad \text{amperes per conductor} \quad (\mathbf{6})$$

The equations for the voltage E_{b1}, and current I_{b1}, etc., at an intermediate point or points where the line characteristics change, are of the same form as (**5**) and (**6**).

Note that $Y = G + j\,B$, the admittance of the line, (**7**)
and $Z = R + j\,X$, the impedance of the line, (**8**)

The series in $Y\,Z$ are very convergent at commerical

frequencies and can be quickly evaluated. It may be noted that

$$1 + \frac{Y Z}{2} + \frac{Y^2 Z^2}{2 \times 3 \times 4} + \ldots = \cosh \sqrt{Y Z} \quad (9)$$

and

$$1 + \frac{Y Z}{2 \times 3} + \frac{Y^2 Z^2}{2 \times 3 \times 4 \times 5} + \ldots = \frac{\sinh \sqrt{Y Z}}{\sqrt{Y Z}} \quad (10)$$

Current in secondary of supply transformers $= I_c$ (11)

Voltage induced in supply transformers

$$E_d = E_c + 1/2\, I_c\, (R_{ts} + j\, X_{ts})$$

volts to neutral (12)

Current in primary of supply transformers

$$I_d = I_c + E_d\, (G_{ts} + j\, B_{ts})$$

amperes per conductor (13)

Voltage at generator terminals

$$E_s = E_d + 1/2\, I_d\, (R_{ts} + j\, X_{ts})$$

volts to neutral (14)

Current at generator terminals

$C + j\, D = I_d$ amperes per conductor (15)

The voltage and current at the generator terminals may thus be found in terms of P, Q and numerical quantities. It is noteworthy that no trigonometrical calculations are required, but only the multiplying of complex quantitites, for which a slide rule is sufficient. The voltage E remains the reference vector throughout the entire calculation.

Let $E_s = E' + j\, E'' + (P + j\, Q)\, (R' + j\, X')$

volts to neutral (16)

where numerical values have been found for the letters with dashes, from (14).

Equation (16) is of exactly the same form as the equation for a transmission line alone, not including transformers. A circle diagram may therefore be drawn for the complete transmission system indicated in Fig. 1, in which E_s and E are voltages kept constant by means of synchronous condensers. Such a diagram will indicate the kv-a. required from the condensers for any given load.

If, as is sometimes done, the voltage at the supply end is kept constant on the high tension side of the step-up transformers, E_s, the constant supply voltage, would be in the place occupied by E_c, Fig. 1.

From equation (16) the absolute value of the supply voltage E_s may be obtained. Thus,

$$E_s^2 = (E' + P\, R' - Q\, X')^2 + (E'' + P\, X' + Q\, R')^2 \quad (17)$$

In the case of a constant-voltage line, P and Q are the only variables.

Equation (17) is the equation of a circle. It reduces to

$$\left(P + \frac{E' R' + E'' X'}{R'^2 + X'^2}\right)^2 + \left(Q - \frac{E' X' - E'' R'}{R'^2 + X'^2}\right)^2 - \frac{E_s^2}{R'^2 + X'^2} = 0 \quad (18)$$

Since P and Q represent currents, equation (18) should be multiplied throughout by

$$\frac{3\, E}{1000} \quad (19)$$

to give a circle showing the relation between kw. and reactive kv-a. at the receiver end of the constant-voltage line.

The center of the circle is the point (a', b') where

$$a' = - \frac{3\, E}{1000} \; \frac{E' R' + E'' X'}{R'^2 + X'^2} \text{ kw.} \quad (20)$$

$$b' = + \frac{3\, E}{1000} \; \frac{E' X' - E'' R'}{R'^2 + X'^2} \text{ kv-a.} \quad (21)$$

The radius is

$$c' = + \frac{3\, E}{1000} \; \frac{E_s}{\sqrt{R'^2 + X'^2}} \text{ kv-a.} \quad (22)$$

In order to plot the reactive kv-a. required from the synchronous condensers, first draw a straight line at

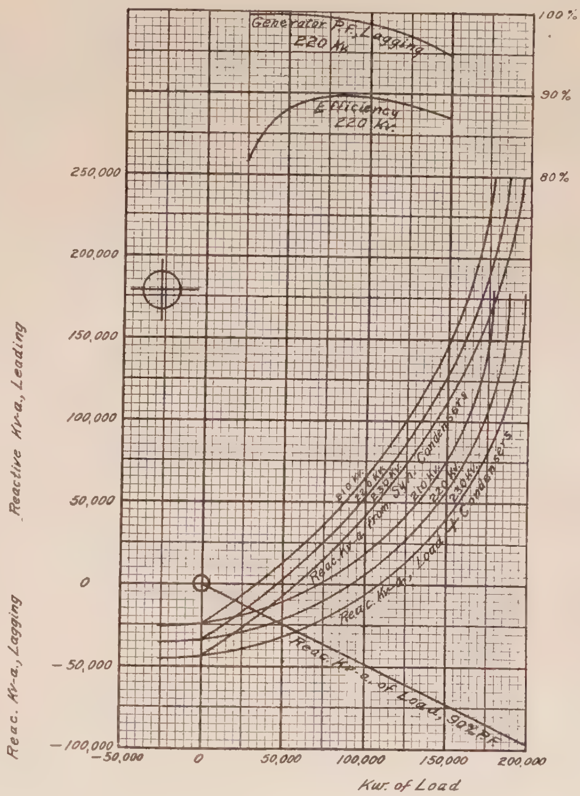

FIG. 2—CIRCLE DIAGRAM FOR 220,000-VOLT, CONSTANT-VOLTAGE TRANSMISSION LINE

(See example 1)

an angle θ below the base line, where $\cos\theta$ is the power factor lagging, of the load. If the power factor is not the same at all loads, the line will not be straight, but will be a curve showing the reactive kv-a. of the load from no load to full load. By means of a pair of dividers add the reactive kv-a. of the load to the corresponding ordinate of the circle, thus plotting the curve of kv-a. required from the synchronous condensers. See Fig. 2.

Theoretical Limit of Load, in Kilowatts

Maximum Load $= c' + a'$ kw. (**23**)

This is numerically less than c' since a' is a negative quantity. It may read from the circle diagram as it is the farthest distance to the right reached by the circle.

Calculated Value of Reactive Kv-a. The method described in this article is not necessarily a graphical method. It is possible to calculate the reactive kv-a. directly, which is sometimes desirable in order to obtain a more precise result than that obtained graphically from the diagram. A direct calculation made in this way is less work than a "trial and error" method, which would generally involve calculating the problem more than once.

The value of the reactive kv-a., $\frac{3\,E\,Q}{1000}$, for a given power load $\frac{3E\,P}{1000}$, may be found from the following equation:

$$\left(b' - \frac{3\,E\,Q}{1000}\right)^2 = c' - \left(\frac{3\,E\,P}{1000} - a'\right)^2 \qquad (\mathbf{24})$$

The reactive kv-a. required from the synchronous condensers are equal to

$$\frac{3\,E\,Q}{1000} + \frac{3\,E\,P}{1000}\,\frac{\sin\theta}{\cos\theta} \quad \text{kv-a.} \qquad (\mathbf{25})$$

where the power load is $\frac{3\,E\,P}{1000}$ kw. at a lagging power factor $\cos\theta$. It should be remembered that b' is a positive quantity and a' is a negative quantity. It is worth while checking the results of equations (**24**) and (**25**) by drawing the circle diagram and obtaining the same results graphically.

Concentric Circles. Since a' and b' which give the center, are independent of the constant supply voltage E_s, and since the radius c' is directly proportional to E_s, it is evident that a number of circles corresponding to different values of E_s may be drawn about the same center. See Fig. 2.

Total Losses.

Let $A = E' + P\,R' - Q\,X'$ volts to neutral (**26**)

and $B = E'' + P\,X' + Q\,R'$ volts to neutral (**27**)

The losses in the transmission system equal

$$\frac{3}{1000}\,(A\,C + B\,D - E\,P) \quad \text{kw.} \qquad (\mathbf{28})$$

This does not include the generator losses. When the constant voltage E_s is on the high tension side of the step-up transformers the losses in the step-up transformers are not included in expression (**28**). As mentioned before, an average value was assumed for the transformer core loss and the condenser loss. The quantities C and D are found from equation (**15**).

Efficiency of the Transmission System.

$$\text{Efficiency} = \frac{100\,E\,P}{A\,C + B\,D} \quad \text{per cent} \qquad (\mathbf{29})$$

Kw. at supply end

$$\frac{3}{1000}\,(A\,C + B\,D) \quad \text{kw.} \qquad (\mathbf{30})$$

Kv-a. at supply end

$$\frac{3\,E_s\,\sqrt{C^2 + D^2}}{1000} \quad \text{kv-a.} \qquad (\mathbf{31})$$

Power factor at supply end

$$\frac{100\,(A\,C + B\,D)}{E_s\,\sqrt{C^2 + D^2}} \quad \text{per cent} \qquad (\mathbf{32})$$

The "supply end" is the point where the voltage E_s is kept constant. If this at the generator terminals, as indicated in Fig. 1, expression (**32**) gives the power factor of the generator load. Whether this is leading or lagging must be determined from the following expression:

Reactive kv-a. at supply end

$$\frac{3}{1000}\,(A\,D - B\,C) \quad \text{kv-a.} \qquad (\mathbf{33})$$

When this quantity is positive the reactive kv-a. and the power factor are leading, and when it is negative, they are lagging.

Example I

Length of line = 200 miles

Frequency = 60 cycles

$R + j\,X = 23.2 + j\,160$ ohms

$Y = +j\,0.00106$ mho

$1 + \frac{Y\,Z}{2} + \ldots = 0.91637 + j\,0.01195$

$1 + \frac{Y\,Z}{2.3} + \ldots = 0.97197 + j\,0.00403$

$P_c = 8.66$ amperes

$R_{tr} + j\,X_{tr} = 1.33 + j\,24.0$ ohms

$G_{tr} + jB_{tr} = 0.000{,}022{,}5 - j\,0.000{,}187{,}5$ mho

$R_{ts} + j\,X_{ts} = 1.61 + j\,29.0$ ohms

$G_{ts} + j\,B_{ts} = 0.000{,}018{,}6 - j\,0.000{,}155{,}0$ mho

$E = 115{,}470$ volts to neutral (line voltage 200,000)

$I_a = P + j\,Q + 8.7$

$E_a = 115{,}480 + j\,100 + (P + j\,Q)\,(0.7 + j\,12.0)$

$I_b = (P + j\,Q)\,(1.002 + j\,0.0002) + 11.3 - j\,21.6$

$E_b = 115{,}740 + j\,220 + (P + j\,Q)\,(1.3 + j\,24.0)$

$E_c = 109{,}680 + j\,2870 + (P + j\,Q)\,(22.9 + j\,178.0)$

$I_c = (P + j\,Q)\,(0.894 + j\,0.013) + 9.9 + j\,99.5$

$E_d = 108{,}240 + j\,3090 + (P + j\,Q)\,(23.4 + j\,191.0)$

$I_d = (P + j\,Q)\,(0.924 + j\,0.013) + 12.4 + j\,82.8$

$E_s = 107{,}050 + j\,3340 + (P + j\,Q)\,(23.9 + j\,204.4)$

$\quad = E' + j\,E'' + (P + j\,Q)\,(R' + j\,X')$

$a' = -\,26{,}600$ kw.

$b' = 178{,}300$ kv-a.

$c' = 213{,}800$ kv-a.

when $E_s = 127{,}020$ volts to neutral (line voltage $= 220{,}000$). See Fig. 2, which shows the desired characteristics of the system.

Exciter Instability

BY R. E. DOHERTY
Associate, A. I. E. E.
Engineer, General Electric Co., Schenectady, N. Y.

PART I—DISCUSSION OF THE PROBLEM

A. Introductory

INSTABILITY of an exciter has come to have a number of meanings: (1) large change in voltage for a small change in load; (2) creeping of voltage, up or down, without apparent cause; (3) temporary removal, partial or total, or even reversal of the excitation accompanying sudden short circuit of the alternator; (4) slow oscillation, or possibly reversal, of excitation following a sudden readjustment of either the shunt field or alternator field rheostat;[1] (5) "grabbing" the load, etc. when in parallel with other exciters. The last mentioned trouble, which is experienced largely, although not altogether, on compound-wound machines does not occur if respect is given to well-known characteristics of direct-current machines as discussed in any text book on the subject. Therefore this paper deals only with the first four phenomena mentioned above.

Experience. All these phenomena have occurred in actual practise. While they have been relatively rare and not confined to exciters of any particular manufacture, there have been enough cases where the consequences have been serious, such as the shut-down of large generating units, to warrant investigation into the causes and character of the phenomena.

Experience has shown that these phenomena occur when the exciter is operating at low magnetic densities; that is, below or near the bend in the saturation curve as at *e* or below, in Fig. 1.

Historical. In 1920 a number of Institute papers[2] were read on exciters and excitation systems. These papers were largely statements of experience and of opinions as to the factors which should predominate in the selection of an excitation system. One of them[3] however, dealt fully with certain phases of exciter design, particularly with reference to successful operation with automatic voltage regulators. In the same year a paper by Kelen[4] discussed the reversal and loss of residual magnetism of exciters, giving equations which showed voltage reversal, under a certain assumed current transient. However, it appears that there has not been a comprehensive mathematical study of the particular system of circuits involved in this problem to determine the behavior of the exciter under conditions which may arise in practise.

Scope. The present investigation comprises (a) a mathematical study of circuits involved, as shown in Fig. 2, assuming the exciter is operating within the range of the straight portion of the saturation curve; and (b) an experimental confirmation of the calculated results. From these two viewpoints it is possible to draw definite conclusions as to the influence upon

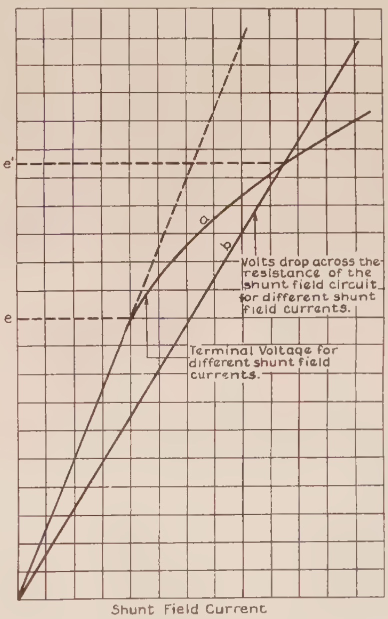

Fig. 1

stability, of the different design features of the exciter and alternator and of the circuits involved.

B. Form of Equation

The most interesting and fundamental result of the investigation is the fact that the differential equation relating the alternator field current with time, is identical in form with the classic differential equation of the electric circuit involving resistance, inductance and capacity. Thus in the present case the equation relating the alternator field current with time is,

$$\frac{d^2 i_2}{d t^2} + \alpha \frac{d i_2}{d t} + \beta i_2 = A \quad \text{(amperes/sec.}^2\text{)} \qquad (7)$$

Presented at the Pacific Coast Convention of the A. I. E. E., Vancouver, B. C., August 8-11, 1922.

1. "Reversal of Exciter Polarity" M. A. Walker, *Power*, June 12, 1917, V. 45 pp. 792-793.

"Trouble with Directly Connected Exciters Due to Polarity Reversal" G. Rutherford, *Electrical World*, Mar. 18, 1916. V. 67, pp. 658, 659.

2. These are given in the accompanying bibliography.

3. "Application of D-C. Generators to Exciter Service," by C. A. Boddie and F. L. Moon, from A. I. E. E. Journal, Vol. 39, 1920, pp. 1595-1616.

4. Elektrotechnik und Maschinenbau, May 16, 1920, V. 38, pp. 225-226.

where

i_2 = alternator field current

t = time

α and β = constants depending upon circuit constants as defined by equations (**8**) and (**9**)

A = constant depending upon the *sustained* value of exciter voltage as defined by equation (**10**).

The classic equation of the electric circuit involving resistance, inductance and capacity is

$$\frac{d^2 i}{d t^2} + \alpha_c \frac{d i}{d t} + \beta_c = A_c \qquad \text{(amperes/sec.}^2\text{)}$$

where i = current in the circuit

t = time

α_c = constant = r/L

β_c = constant = $\dfrac{1}{L C}$

A_c = constant = E/L

r, L and C = circuit constants

E = constant rate at which the impressed voltage increases.[5]

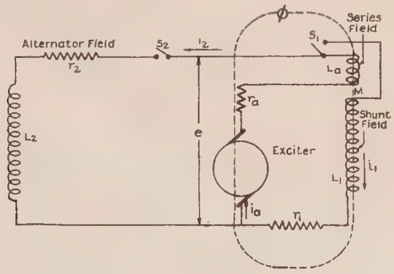

FIG. 2

Since the equations in the two cases are identical, there must, of course, be found in the solution of the former the same oscillations and transients as are given in the well known solution of the latter. That is, the present case falls in the category of transients designated by Steinmetz as "double energy" transients.[6] In other words, if on the one hand an exciter is closed upon an alternator field circuit, and on the other hand, a voltage which increases in direct proportion to time is suddenly impressed upon a circuit containing resistance, inductance and capacity, then one may expect the current as related to time to be of precisely the same form in either case. Depending upon the relation of circuit constants the current may gradually build up to a final value, or may finally reach this value after a number of progressively smaller oscillations.

Transients of the same character will also occur if a sudden readjustment of circuit constants is made, which is equivalent to suddenly impressing a different voltage. Thus Fig. 6 shows a transient oscillation following the application of the exciter voltage to an alternator field circuit; Fig. 14, the oscillation following a sudden readjustment (increase in resistance) of shunt field rheostat; Fig. 16, the gradual (logarithmic) decrease of current to a final value following a similar sudden increase in shunt field rheostat, but with different circuit constants; Fig. 9, the surge and decay of current following a sudden short circuit of the alternator, which, as explained in Part II, is equivalent to a sudden change in circuit constants.

It will be observed that while these transients are of the same form as those of the electric circuit containing resistance, inductance and capacity, they are of much longer duration and lower frequency.

C. CONDITIONS FOR INSTABILITY

Conditions of instabilty are; low magnetic densities,[7] in combination with one or more of the following:

(a) low residual voltage.

(b) relatively large voltage drop in the armature, due either to large demagnetizing component of armature reaction or to large ohmic resistance in the armature circuit between the points where the shunt field terminals are connected.

(c) relatively large inductance in the load circuit, such as always exists in the alternator field.

(d) alternator transient of greater duration than exciter transient.

(e) excessive series field strength.

Discussion of Conditions. Consider the conditions of low magnetic densities. It is well known that a saturated exciter is usually stable since it requires a relatively large change in ampere turns to produce a given change in the magnetic flux. The degree of stability is roughly gauged by the magnitude of the angle θ, Fig. 3. The operating point p on the saturation curve is determined by the condition that the $r\,i$ drop of the shunt field circuit shall equal the terminal voltage of the exciter. Above that point, the terminal voltage is less than that required to sustain the shunt field current; below, it is more than required. That is, the greater the angle θ the more stable the exciter. It is thus obvious from Fig. 3 that on the straight portion of the saturation curve, the stability

5. That is, $e = E\,t$. This merely determines the final value of current, and has nothing to do with the character of the transient, since the transient is determined by making $A_c = O$. It was so chosen in this illustration to make the two cases exactly parallel, including both the transient and the final value.

6. In the circuit containing r, L and C, the "double energy" refers to the two forms of energy storage $1/2\,L\,I^2$ and $1/2\,C\,E^2$.

In the present case, while there is no condenser capacity involved, and therefore no electrostatic energy, there are nevertheless two different magnetic circuits—alternator and exciter fields—in which energy can be stored. Obviously, in an oscillation all of the relatively large energy in the alternator field cannot be transferred to the small exciter field. Most of it is dissipated as $i^2\,r$. Only a small percentage is transferred to the exciter, but it is sufficient to start the exciter to build up again, the energy supplying the subsequent oscillations thus coming from the mechanical drive of the exciter.

7. That is, operation on straight portion of the saturation curve.

is low; and if it were not for the residual voltage e_0, θ would be zero and the exciter would be inoperative; that is, a single value of shunt field resistance would correspond to *all* voltages on the straight portion of the curve.

Thus it follows that residual voltage is essential to stability in operation on the straight portion of the curve. However, operation beyond the bend, that is involving a significant degree of saturation, would be stable with zero residual voltage.

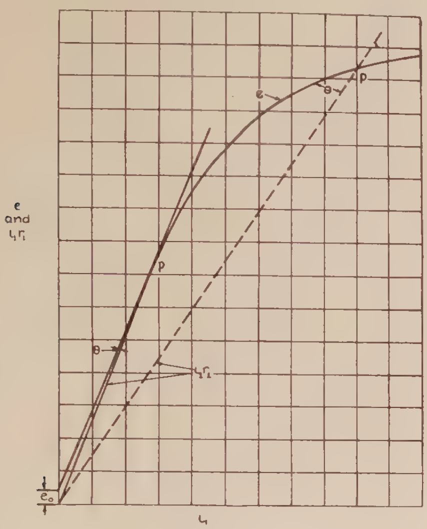

Fig. 3

The condition of large voltage drop in the armature means a large droop in the volt-ampere characteristic of the exciter, Fig. 4. Curves a and b are volt-ampere characteristics of the particular exciter used in this investigation; a being for normal brush position, b for a forward shift of 2.7 mechanical degrees. Curve c is the volt-ampere characteristic of the receiving circuit, that is, it gives the voltage required to maintain the current i_2 in the resistance r_2 of the receiving circuit, which in the present problem is the alternator field circuit. The exciter must obviously operate at the intersection of the volt-ampere characteristics of the exciter and receiving circuit. The unstable condition of relatively large voltage drop in the armature is thus illustrated in Fig. 4 by the intersection of b and c, that is the point n. Stability could evidently be obtained by increasing r_2, which would increase the slope of c, moving n upward to a less steep portion of curve b; or, with the same r_2, a change in the exciter characteristic to correspond to a, thus giving the stable intersection m.[8]

The existence of a large inductance in the load circuit, which means relatively large magnetic energy storage is the fundamental condition for the occurrence of "double energy" transients as distinguished from slow "creeping" of voltage. This energy storage makes possible a "pump back" of power into the exciter under certain conditions. For instance, any sudden condition which tends to lower the exciter voltage—such as the large load current thrown on the exciter when the alternator is short-circuited, or a sudden increase in the shunt field rheostat, or a decrease in the alternator field rheostat—such conditions cause the load current of the exciter to decrease. But the large inductance in the alternator field will not permit the current to decrease as rapidly as it would if its decrease were determined by the exciter alone. Thus under certain conditions the alternator field tends to hold the decreasing load on the exciter always at a higher value than the decreasing voltage of the exciter could alone maintain, and when zero magnetic flux in the exciter is reached, the current is maintained through the armature by the external voltage generated by the alternator field. This means that the voltage across the armature and therefore across the shunt field is reversed, and thus the voltage builds up reversed. While it is reversed, and before the decreasing current reaches zero, the alternator field is obviously supplying power to the exciter. After reversal the alternator field inductance holds the current always at a *lower* value than would exist by the exciter voltage alone. Therefore such a condition makes it impossible, theoretically, for the exciter to ever reach equilibrium. Actually, of course, it is reached after a few oscillations, as shown in Fig. 7.

The condition under which this reversal may occur is that the duration of the alternator transient is greater than that of the exciter. It is thus a race between these two transients. Obviously if the alternator tends to reach equilibrium before the exciter, its influence in holding up the load on the exciter will have disappeared before the exciter voltage reaches zero, and the exciter, once more on its own resources, if only for a moment, will again build up. Thus the inductance of the alternator field makes possible oscillations and voltage reversals; and the condition under which this is possible is that the duration of the alternator transient is greater than that of the exciter.

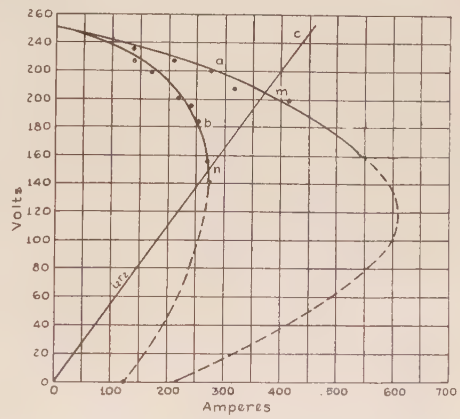

Fig. 4

Excessive series field strength obviously gives to the exciter characteristics approaching those of the series generator. Such characteristics may be obtained as

8. This, of course, is merely reciting, in the interest of completeness, a fact already given in text books.

well by connecting a normally designed exciter on a receiving circuit of too low resistance, as by designing for too great series field strength. For instance, a 125-volt exciter connected to an alternator field requiring only 60 volts for normal exciting current, (rated current on exciter) means practically doubling the relative strength of the series field; and quadrupling the strength, assuming the same kilowatts excitation.

D. Causes of Instability

The principal causes are:

(a) speed transients

(b) temperature transients

(c) slight undulations in exciter voltage, which may modify the local effect of hysteresis and thus cause a gradual shift in the saturation curve and a corresponding change in voltage.

(d) sudden, relatively large change in rheostat setting.

(e) short circuit of the alternator.

Discussion of Causes. The first three causes may produce voltage "creeping," the last two "double energy" transients. The effect of speed transients, which is to shift the operating point p Fig. 3 on the saturation curve, is discussed in the paper by Boddie and Moon, loc. cit.

Temperature transients produce slow voltage changes in a similar manner. Rising temperature, and therefore increasing resistance, in the shunt field circuit slowly increases the slope of the $i_1 r_1$ line Fig. 3, but does not change the saturation curve. It thus shifts the point p downward.

Slight undulations in the exciter voltage[9] mean repeated traversal of the local hysteresis loop, which, by this process, moves the center of the loop gradually toward the *average* saturation curve, thus in effect eliminating or seriously reducing the residual magnetism. The result is a large downward shift in the operating point p.

A sudden change in rheostat setting of either the shunt or alternator field circuit, is equivalent to suddenly impressing a different voltage, and therefore under conditions discussed in the foregoing, may cause oscillation and reversal of the excitation. This may easily occur on hand controlled exciters if the resistance steps in the shunt field rheostat are too large, or if the operator suddenly makes too large an adjustment.

Short circuit, or a sudden large increase in inductive load on the alternator, induces an increase in the direct current[10] through the exciter armature—that is, an increase in load, the greater the current increase in the alternator armature. This initiates the "double energy" transients already discussed.

E. Stabilizers

Voltage "creeping" can be minimized by special design to increase the angle θ Fig. 3 at low voltages. The same result can be obtained by a few cells of a storage battery in series with the shunt field, thus giving the effect of greater residual voltage, e_0, Fig. 3. Separate excitation of the shunt field by storage battery gives practically perfect stability, but of course involves obvious disadvantages.

The most effective stabilizer against shocks due to alternator short circuits, or sudden change in circuit constants, is the series field. By minimizing the voltage drop of the exciter, that is the drop in voltage impressed across the shunt field terminals, and therefore also minimizing the tendency toward a further reduction of exciter magnetic flux, the foremost factor in causing removal or reversal of excitation is practically eliminated. The influence of the series field in these cases is illustrated by Figs. 9 and 10, showing respectively the excitation following a sudden short circuit of the alternator, first without series field, then with series field. Figs. 14 and 16 show the excitation following a change in the setting of the shunt field rheostat, first without series field, then with. That is, a properly designed series field appears to be the greatest protection against instability following shocks, particularly against a serious decrease of excitation, and therefore of synchronizing power of large generating units under short-circuit conditions.

The next is the automatic voltage regulator. Its effect is to instantly decrease the shunt field resistance, that is, to greatly decrease the slope of $i_1 r_1$ Fig. 3, thus adjusting the exciter instantly for a greater load. In other words, when an exciter transient starts, the regulator instantly introduces a rapid transient in the opposite direction, and therefore stabilizes the exciter under most conditions arising in practise. Its influence on the exciter following a short circuit of the alternator is shown in Fig. 13. The combination, therefore, of a properly designed compound wound exciter controlled by an automatic voltage regulator, gives excellent stability.

Resistance in the alternator field circuit increases stability by shortening the alternator transient and lengthening the exciter transient[11], thus doubly increasing the ratio of the durations of these transients. If sufficient resistance is put in the alternator field circuit, the exciter voltage may reach values above the bend of the saturation curve, and so further increase the stability by saturation. Figs. 9 and 11 show respectively the transient following a short circuit on the alternator, first without and then with a rheostat in the alternator field circuit.

F. Summary

1. The form of equation for exciter voltage and current is the same as the well known equation for the

9. This might be caused by speed variations as on direct-connected or belted exciters driven by reciprocating machines such as steam or gas engines, or compressors.

10. There is also an alternating component, but its frequency is too high to significantly affect the exciter flux.

11. By causing the exciter to operate at a higher voltage, thus requiring lower resistance in the shunt field circuit.

electric circuit containing resistance, inductance and capacity. Hence the same form of oscillations and transients are involved, the only difference being that in the present case the duration of the transients is much longer.

2. Instability may occur when the exciter is operating on the straight part of the saturation curve, if in addition some combination of the following conditions exists:

(a) very low residual voltage—say 1 per cent or so.

(b) a relatively large voltage drop in the armature.

(c) large inductance in the load circuit, as always exists in the alternator field.

(d) alternator transient of greater duration than the exciter transient.

(e) excessive series field strength.

3. Instability may be classed, for convenience, under two headings: (a) voltage "creeping," and (b) "double energy" transients. The former may be caused by slight speed transients of the exciter; or by temperature transients causing corresponding resistance transients in the shunt field circuit; or by hysteresis effects which may be caused by small undulations in the exciter voltage. The "double energy" transients, such as oscillations and reversal of excitation, may be initiated by a shock, such as a short circuit on the alternator, or sudden, relatively large change circuit in constants, for instance a large change in resistance in the shunt field circuit.

4. The exciter can be stabilized against voltage "creeping," (a) by special design to increase the angle θ Fig. 3 at low voltage; (b) by a few battery cells connected in series with the shunt field, thus giving the effect of greater residual voltage e_0 Fig. 3; (c) by separately exciting the shunt field; (d) by automatic voltage regulator; or (e) by rheostat in the alternator field, requiring the exciter to operate at voltages involving saturation. It can be stabilized against "double energy" transients (a) by a properly designed series field; (b) automatic voltage regulator, or both (a) and (b); (c) alternator field rheostat.

The author wishes to acknowledge the valuable assistance of Mr. R. F. Franklin in the preparation of this paper.

PART II—EQUATIONS AND TESTS

A. Mathematical Analysis

Equation for Alternator Field Current. The following assumptions are made:

Constant speed of exciter

Operation below bend of saturation curve

Residual voltage, constant

Resistance of armature circuit, constant.

Fig. 2 shows the arrangement of circuits and defines the different currents, voltages and circuit constants.[12] The differential equations for the voltage in the different circuits are as follows:

Alternator field circuit,

$$e = i_2 r_2 + L_2 \frac{d\, i_2}{d\, t} \qquad \text{(volts)} \qquad (1)$$

Exciter shunt field circuit,

$$e = i_1 r_1 + L_1 \frac{d\, i_1}{d\, t} + M \frac{d\, i_a}{d\, t} \qquad \text{(volts)} \qquad (2)$$

Exciter armature circuit,

$$e = e_a - i_a r_a - M \frac{d\, i_1}{d\, t} - L_a \frac{d\, i_a}{d\, t} \qquad \text{(volts)} \qquad (3)$$

Also,

$$i_a = i_1 + i_2 \qquad \text{(amperes)} \qquad (4)$$

where,

e_a = generated voltage of exciter

r_a = ohmic resistance of exciter armature circuit[13] including series and interpole fields, if any.

Assuming that the exciter is working at low magnetic densities, *i. e.*, on the straight part of the saturation curve, the equation for the generated voltage is,

$$e_a = e_0 + K \phi \qquad \text{(volts)} \qquad (5)$$

where,

ϕ = flux per pole in magalines

K = total generated armature volts per megaline of flux per pole.

e_0 = residual voltage.

The flux ϕ is a function of both the shunt field current and the armature current. Thus,

$$\phi = k_1 i_1 + k_a i_a \qquad \text{(megalines)} \qquad (6)$$

where,

k_1 = megalines per pole per shunt field ampere

k_a = megalines per pole per ampere in the armature circuit. It is thus the net result of the armature, interpole and series field magnetomotive forces, and may therefore be either positive or negative. It is positive if magnetizing, *i. e.*, if it adds to the shunt field flux; and negative if demagnetizing.

Solving the above simultaneous equations for the relation between i_2 and t, the following well known differential equation is obtained:

$$\frac{d^2\, i_2}{d\, t^2} + \alpha \frac{d\, i_2}{d\, t} + \beta\, i_2 = A \qquad \text{(amperes/sec.}^2\text{)} \qquad (7)$$

where,

$$\alpha = \frac{r_2 (L_a + M) + r_1 (L_a + L_2) + [r_a - K (k_1 + k_a)] (L_2 - M) - [K k_a - (r_a + r_2)] (L_1 + M)}{(L_2 - M) (L_a + M) + (L_1 + M) (L_a + L_2)} \qquad (1/\text{sec.}^2) \qquad (8)$$

$$\beta = \frac{- K (k_1 r_2 + k_a r_2 + k_a r_1) + r_a r_2 + r_1 r_a + r_1 r_2}{(L_2 - M) (L_a + M) + (L_1 + M) (L_a + L_2)} \qquad (1/\text{sec.}^2) \qquad (9)$$

12. For detailed definition see "notation."

13. Armature circuit up to the points where the shunt field terminals are connected.

$$A = \frac{e_0 r_1}{(L_2 - M)(L_a + M) + (L_1 + M)(L_a + L_2)}$$
(amperes/sec.^{2}) (**10**)

Equation (**7**) is a second order, linear differential equation whose solution, as given in all texts on differential equations, is,

$$i_2 = C_1 \epsilon^{m_1 t} + C_2 \epsilon^{m_2 t} + A/\beta$$
(amperes) (**11**)

where, C_1 and C_2 are integration constants, and

$$m_1 = -\alpha/2 + \sqrt{\alpha^2/4 - \beta} \quad (1/\text{sec.}) \quad (\mathbf{12})$$

$$m_2 = -\alpha/2 - \sqrt{\alpha^2/4 - \beta} \quad (1/\text{sec.}) \quad (\mathbf{13})$$

Let,

$$\gamma = \sqrt{\alpha^2/4 - \beta} \quad (1/\text{sec.}) \quad (\mathbf{14})$$

and,

$$i_0 = A/\beta$$

$$= \frac{e_0}{(r_2 + r_a) + r_2/r_1\,[r_a - K(k_1 + k_a)] - K k_a}$$
(amperes) (**15**)

Substituting these relations in (**11**) the final equation for the alternator field current becomes,

$$i_2 = \epsilon^{-\frac{\alpha}{2} t}\,(C_1 \epsilon^{\gamma t} + C_2 \epsilon^{-\gamma t}) + i_0$$
(amperes) (**16**)

Integration Constants

The integration constants C_1 and C_2 will be determined for four different boundary conditions.

Case I. Switches S_1 and S_2, Fig. 2, are closed at the same instant.

Thus at $t = 0$, $i_1 = 0$, $i_2 = 0$, $e = e_0$.

Hence from (**16**)

$$C_1 + C_2 + i_0 = 0. \quad (\text{amperes}) \quad (\mathbf{17})$$

Another relation between C_1 and C_2 is necessary. This is given by equation (**1**). Since at $t = 0$, $i_2 = 0$.

$$\frac{d\,i_2}{d\,t} = e_0/L_2 \quad (\text{amperes/sec.}) \quad (\mathbf{18})$$

Differentiating (**16**) and substituting $t = 0$,

$$\frac{d\,i_2}{d\,t} = m_1 C_1 + m_2 C_2 \quad (\text{amperes/sec.}) \quad (\mathbf{19})$$

Equating (**18**) and (**19**)

$$m_1 C_1 + m_2 C_2 = \frac{e_0}{L_2} \quad (\text{amperes/sec}). \quad (\mathbf{20})$$

Solving (**17**) and (**20**) for C_1 and C_2, and substituting (**12**), (**13**) and (**14**)

$$\left.\begin{aligned} C_1 &= \frac{e_0/L_2 - i_0(\gamma + \alpha/2)}{2\gamma} \\ C_2 &= -\frac{e_0/L_2 + i_0(\gamma - \alpha/2)}{2\gamma} \end{aligned}\right\} \quad (\text{amperes}) \quad (\mathbf{21})$$

Case II. After switch S_1 has been closed and the exciter voltage has built up to its permanent value, close S_2, Fig. 2.

Thus at $t = 0$, $i_2 = 0$, $e = e'$ where e' is the exciter terminal voltage previous to closing S_2. Hence from (**16**)

$$C_1 + C_2 + i_0 = 0 \quad (\text{amperes}) \quad (\mathbf{22})$$

and from (**1**)

$$\frac{d\,i_2}{d\,t} = e'/L_2 \quad (\text{amperes/sec.}) \quad (\mathbf{23})$$

Since (**22**) and (**23**) are identical in form with (**17**) and (**18**), the integration constants for Case II are, by analogy with (**21**),

$$\left.\begin{aligned} C_1 &= \frac{e'/L_2 - i_0(\gamma + \alpha/2)}{2\gamma} \\ C_2 &= -\frac{e'/L_2 + i_0(\gamma - \alpha/2)}{2\gamma} \end{aligned}\right\} \quad (\text{amperes}) \quad (\mathbf{24})$$

Case III. Switches S_1 and S_2 have been closed and the currents i_1 and i_2 have reached the permanent values i_{11} and i_0 respectively. Short circuit occurs on alternator.

In this case the boundary values are taken as those existing the instant after the alternator short circuit and are determined by the condition that neither the magnetic interlinkages with the alternator field winding nor that with the shunt field circuit can change, in the first instant, from the values existing before the short circuit occurred. That is, the alternator field flux which, before short circuit traversed the low-reluctance path through the armature iron, inductance L_2, must now pass through the higher reluctance of the leakage paths, inductance L_2', between field and armature windings. But since the magnetic interlinkages of this circuit[14] has not changed.

$$L_2 i_0 = L_2' i_2'$$

where $\quad i_2' = L_2/L_2'\, i_0 \quad$ (amperes) (**25**)

There is also, of course, a large alternating component of current through the exciter armature, but its effect on the exciter is practically negligible, since the frequency is so high. Likewise, since the flux ϕ[15] linked with the shunt field circuit has not changed, it is by (**4**), (**6**) and (**25**)

$$\Phi = \underbrace{k_1 i_{11} + k_a(i_{11} + i_0)}_{\text{before}} = \underbrace{k_1 i_{11}' + k_a(i_{11}' + i_2')}_{\text{after}}$$
(magalines) (**26**)

From (**25**) and (**26**)

$$i_{11}' = i_{11} + i_0(1 - L_2/L_2')\,\frac{k_a}{k_1 + k_a} \quad (\text{amperes}) \quad (\mathbf{27})$$

Thus at $t = 0$, $i_2 = i_2'$, $i_1 = i_{11}'$

From (**16**)

$$C_1 + C_2 + i_0 = i_2' \quad (\text{amperes}) \quad (\mathbf{28})$$

Another relation is necessary. This is given as before, by

$$\frac{d\,i_2}{d\,t}$$

at $t = 0$. Substituting in (**2**) and (**1**) respectively equation (**4**) and the values of i_1 and i_2 at $t = 0$, as determined by (**25**) and (**27**), and equating, a relation

14. Equation (**25**) neglects the relatively small inductance L_a of the exciter armature circuit.

15. Strictly this should be magnetic interlinkages instead of *flux*, since the flux may increase due to partial interlinkages in the leakage paths. However, the approximation is justified in the present case, since the change in flux is relatively very small.

is obtained between $\frac{d\,i_1}{d\,t}$ and $\frac{d\,i_2}{d\,t}$. It is,

$$\frac{d\,i_1}{d\,t} = \frac{i_2\,r_2 - i_{11}'\,r_1}{L_1 + M} + \frac{L_2' - M}{L_1 + M}\,\frac{d\,i_2}{d\,t}$$

(amperes/sec.) (29)

Equating (1) and (3) and substituting (4), (5), (26) and (29),

$$\frac{d\,i_2}{d\,t} = G = \frac{e_0 + i_{11}'\,[K\,(k_1 + k_a) - r_a] + i_2'\,(K\,k_a - r_a - r_2) - \frac{L_a + M}{L_1 + M}\,(i_2'\,r_2 - i_{11}'\,r_1)}{(L_a + L_2') + \frac{L_a + M}{L_1 + M}\,(L_2' - M)}$$

(amperes/sec.) (30)

Thus from (11) and (30)

$$\frac{d\,i_2}{d\,t} = G = m_1\,C_1 + m_2\,C_2 \quad \text{(amperes/sec.)} \quad (31)$$

Solving (28) and (31) for C_1 and C_2, and substituting (12) and (13)

$$\left.\begin{aligned} C_1 &= \frac{G + (i_2' - i_0)\,(\gamma + \alpha/2)}{2\,\gamma} \\ C_2 &= -\frac{G - (i_2' - i_0)\,(\gamma - \alpha/2)}{2\,\gamma} \end{aligned}\right\} \quad \text{(amperes)} \quad (32)$$

In calculating α and β from (8) and (9), the value of leakage inductance L_2' should, of course, be used instead of the total inductance L_2.

Case IV. Switches s_1 and s_2 have been closed and i_1 and i_2 have reached the permanent values i_{11} and i_2'' respectively. The shunt field resistance r_1 is suddenly changed from r_1^0 to r_1'.

As in Case III, boundary values are taken as those existing the instant after r_1 is changed, and are determined by the condition that the magnetic interlinkages of shunt field and alternator field circuits must, for the moment, each remain the same. It is necessary to know i_2 and $\frac{d\,i_2}{d\,t}$ at $t = 0$.

$$i_2 = i_0 \quad \text{and} \quad \frac{d\,i_2}{d\,t} = 0.$$

The latter may not be obvious. In the first instant, that is at $t = 0$, the exciter flux ϕ has not changed. $\frac{d\,\phi}{d\,t}$ is not zero, but at $t = 0$ no appreciable change has occurred. Hence e has not changed, neglecting the insignificant voltage $M\,\frac{d\,i_1}{d\,t}$, and therefore i_2 has not changed.

From (1), $\frac{d\,i_2}{d\,t} = 0$. Therefore from (11) and (16) at $t = 0$,

$$C_1 + C_2 + i_0 = i_2'' \quad \text{(amperes)} \quad (33)$$

$$\frac{d\,i_2}{dt} = m_1\,C_1 + m_2\,C_2 = 0 \quad \text{(amperes/sec.)} \quad (34)$$

Solving (33) and (34) for C_1 and C_2, and substituting (12), (13) and (14),

$$\left.\begin{aligned} C_1 &= \frac{(i_2'' - i_0)\,(\gamma + \alpha/2)}{2\,\gamma} \\ C_2 &= \frac{(i_2'' - i_0)\,(\gamma - \alpha/2)}{2\,\gamma} \end{aligned}\right\} \quad \text{(amperes)} \quad (35)$$

That is, the same as for Case III when $G = 0$. In calculating i_0 from equation (15), substitute r_1' for r_1; in calculating i_2'' from (15), substitute r_1^0 for r_1; and in calculating α and β from (8) and (9) respectively, the total inductance L_2 should be used, as in Cases I and II.

Consider the character of C_1, C_2, m_1 and m_2. These may be either real or imaginary since each contains γ, which may be either real or imaginary depending upon whether $\alpha^2/4$ is greater or less than β. As discussed in texts on differential equations, if the exponent γ is real the solution involves only logarithmic functions, if imaginary it involves a combination of logarithmic and trigonometric functions, *i. e.*, a decaying oscillation.

If γ is real, the form of (16) is satisfactory for numerical calculation. However, if it is imaginary it becomes necessary to rewrite (16) in a different form for calculation.

For the latter case, that is when

$$\alpha^2/4 < \beta$$

let $\gamma' = \sqrt{\beta - \alpha^2/4}$ (1/sec.) (36)

Then $\gamma = j\,\gamma'$ (1/sec.) (37)

The constants of integration in all four cases are of the form

$$\left.\begin{aligned} C_1 &= \frac{a - j\,b}{j\,c} \\ C_2 &= -\frac{a + j\,b}{j\,c} \end{aligned}\right\} \quad \text{(amperes)} \quad (38)$$

where in

Case I

$$\left.\begin{aligned} a &= e_0/L_2 - \alpha/2\,i_0 && \text{(amperes/sec.)} \\ b &= i_0\,\gamma' && \text{(amperes/sec.)} \\ c &= 2\,\gamma' && \text{(1/sec.)} \end{aligned}\right\} \quad (39)$$

Case II

$$\left.\begin{aligned} a &= e'/L_2 - \alpha/2\,i_0 && \text{(amperes/sec.)} \\ b &= i_0\,\gamma' && \text{(amperes/sec.)} \\ c &= 2\,\gamma' && \text{(1/sec.)} \end{aligned}\right\} \quad (40)$$

Case III

$$\left.\begin{aligned} a &= G + \alpha/2\,(i_2' - i_0) && \text{(amperes/sec.)} \\ b &= -\,\gamma'\,(i_2' - i_0) && \text{(amperes/sec.)} \\ c &= 2\,\gamma' && \text{(1/sec.)} \end{aligned}\right\} \quad (41)$$

Case IV

$$\left.\begin{aligned} a &= \alpha/2\,(i_2'' - i_0) && \text{(amperes/sec.)} \\ b &= -\,\gamma'\,(i_2'' - i_0) && \text{(amperes/sec.)} \\ c &= 2\,\gamma' && \text{(1/sec.)} \end{aligned}\right\} \qquad (42)$$

Thus in all four cases the equation for i_2 is by (**16**)

$$i_2 = \epsilon^{-\frac{\alpha}{2}t}\left[\frac{a - j\,b}{j\,c}\,\epsilon^{j\gamma' t} - \frac{a + j\,b}{j\,c}\,\epsilon^{-j\gamma' t}\right] + i_0 \qquad \text{(amperes)} \qquad (43)$$

But, by Euler's relation,

$$\left.\begin{aligned} \epsilon^{j\gamma' t} &= \cos\gamma' t + j\sin\gamma' t \\ \epsilon^{-j\gamma' t} &= \cos\gamma' t - j\sin\gamma' t \end{aligned}\right\} \qquad \text{(numerical)} \qquad (44)$$

Substituting (**44**) in (**43**),

$$i_2 = 2/c\;\epsilon^{-\frac{\alpha}{2}t}\,(a\sin\gamma' t - b\cos\gamma' t) + i_0 \qquad \text{(amperes)} \qquad (45)$$

or, simplifying,[16]

$$i_2 = \frac{2\sqrt{a^2 + b^2}}{c}\,\epsilon^{-\frac{\alpha}{2}t}\sin(\gamma' t + \theta) + i_0 \qquad \text{(amperes)} \qquad (46)$$

where $\theta = \arctan(-\,b/a)$ (radians)

Exciter Voltage

From equation (**1**)

$$e = i_2\,r_2 + L_2\,\frac{d\,i_2}{d\,t} \qquad \text{(volts)} \qquad (1)$$

As discussed in the foregoing, there are two cases to consider: (1) when γ is real, and (2) when γ is imaginary.

(1) when γ is real. Use equation (**16**).

Thus

$$i_2 = \epsilon^{-\frac{\alpha}{2}t}\,[C_1\,\epsilon^{\gamma t} + C_2\,\epsilon^{-\gamma t}] + i_0 \qquad \text{(amperes)} \qquad (16)$$

Differentiating (**16**),

$$\frac{d\,i_2}{d\,t} = \epsilon^{-\frac{\alpha}{2}t}\,[\,(\gamma - \alpha/2)\,C_1\,\epsilon^{\gamma t} - (\gamma + \alpha/2)\,C_2\,\epsilon^{-\gamma t}] \qquad \text{(amperes/sec.)}$$

Hence from (**1**)

$$e = \epsilon^{-\frac{\alpha}{2}t}\,[\,\{r_2 + L_2\,(\gamma - \alpha/2)\,\}\,C_1\,\epsilon^{\gamma t} + \{r_2 - L_2\,(\gamma + \alpha/2)\,\}\,C_2\,\epsilon^{-\gamma t}] + i_0\,r_2 \qquad \text{(volts)} \qquad (47)$$

C_1 and C_2 being determined by—

(21) for Case I.
(24) for Case II.
(32) for Case III.
(35) for Case IV.

(2) when γ is imaginary. Use equation (**45**).

Thus,

$$i_2 = 2/c\;\epsilon^{-\frac{\alpha}{2}t}\,(a\sin\gamma' t - b\cos\gamma' t) + i_0 \qquad \text{(amperes)} \qquad (45)$$

Differentiating (**45**),

$$\frac{d\,i_2}{dt} = \frac{\epsilon^{-\frac{\alpha}{2}t}}{c}\,[\,(2\,\gamma'\,b - \alpha\,a)\sin\gamma' t + (2\,\gamma'\,a + \alpha\,b)\cos\gamma' t] \qquad \text{(amperes/sec.)}$$

Hence, from (**1**)

$$e = \frac{\epsilon^{-\frac{\alpha}{2}t}}{c}\,[\,\{2\,r_2\,a + L_2\,(2\,\gamma'\,b - \alpha\,a)\,\}\sin\gamma' t - \{2\,r_2\,b - L_2\,(2\,\gamma'\,a + \alpha\,b)\,\}\cos\gamma' t] + i_0\,r_2 \qquad \text{(volts)} \qquad (48)$$

where a, b and c are determined by—

(39) for Case I.
(40) for Case II.
(41) for Case III.
(42) for Case IV.

B. Discussion of Assumptions

Fig. 2 shows the circuits considered. The equations therefore apply strictly to an individual exciter connected to an alternator field, and not to a number of exciters in parallel. However, if the exciters in parallel have the same characteristics, and operate at constant speed, as assumed, then the group can be considered as a single unit with constants as resultant of those of the several exciters; and the alternator field connected to the bus can be considered as a single circuit with resultant constants. Then the equations will apply.

However, the object of the equations is much less to calculate the behavior of exciters in service than to investigate and determine, once for all, the factors which cause unstable exciters and the factors which make them stable. Because, if an exciter is stable when operating as an individual unit under the shocks of alternator short-circuit and other conditions, here considered, it may be safely assumed that it will also be stable when in parallel with others.

Do not misunderstand. Load "grabbing," etc., due to lack of respect for fundamental characteristics of d-c. machines when making connections or adjustments of such machines in parallel, is not considered. It is not fair to blame the exciter for "grabbing" the load or reversing if thrown on the bus at too low or too high voltage, or if it is not properly "equalized." No one would blame an engine for running away if its governor were out of adjustment. This sort of "instability" is not considered, and in the other respects which are considered, an exciter which is stable as an individual unit can be regarded as stable also when in parallel.

The fact that the alternators operate in multiple does not significantly affect the behavior of the exciters under the conditions considered.

Constant speed is assumed. A change in speed will produce a transient in the voltage designated in Part I as "creeping." This transient may be determined from the equation by using the value of e_0 and k_1 corresponding to the new speed, and substituting the existing currents, etc., before the change as boundary conditions to determine integration constants. In this type of transient the voltage differences which

16. For plotting results (**45**) is perhaps the better form, because although it requires two curves to be plotted, there is no difficulty in keeping signs straight, as there may be if (**46**) is used.

sustain the transients are very small. In the other type *i. e.*, "double energy" transients, due to shock, such as alternator short circuit, the voltage differences involved in the transients are very large. Therefore in the latter case, any small variations in voltage due to slight speed change, being a small percentage of the large voltage difference involved, do not materially affect the results as calculated on the assumption of constant speed.

Operation on the "straight" part of the saturation curve, and a constant residual voltage are assumed. That is, the saturation curve is expressed by the linear equation (**5**). Actually, the curve, especially on small exciters, is neither absolutely straight at the lower

Tests were made as far as possible under conditions of the four different "Cases"[17] for which integration constants were determined. Change of constants in each different Case[18] was also made with corresponding calculations and tests.

The data substituted in the equations for results to compare with tests, are calculated[19] from designs of the exciter and alternator.

Tests

Case I. Switches S_1 and S_2 closed at the same instant. See Fig. 2.

(a) Shunt exciter[20] with interpoles; brushes two bars (3.5 mechanical degrees) forward[21] *from the neutral position.*

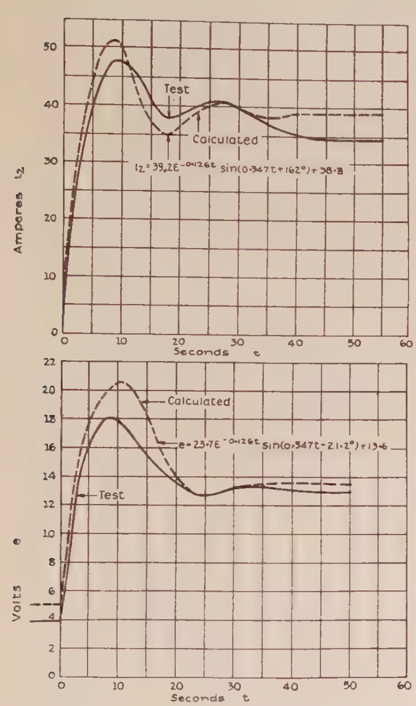

Fig. 5

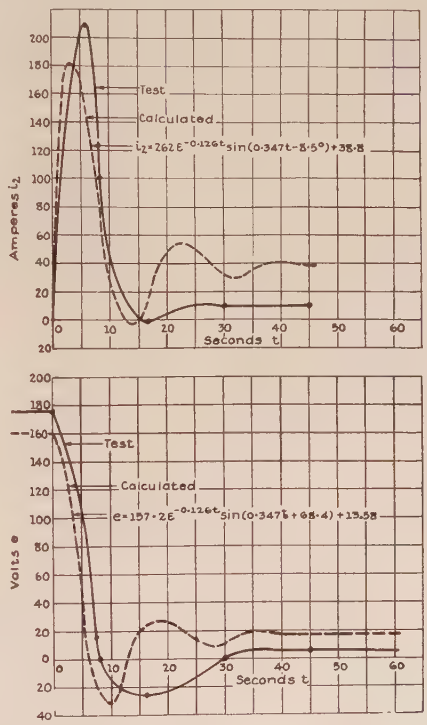

Fig. 6

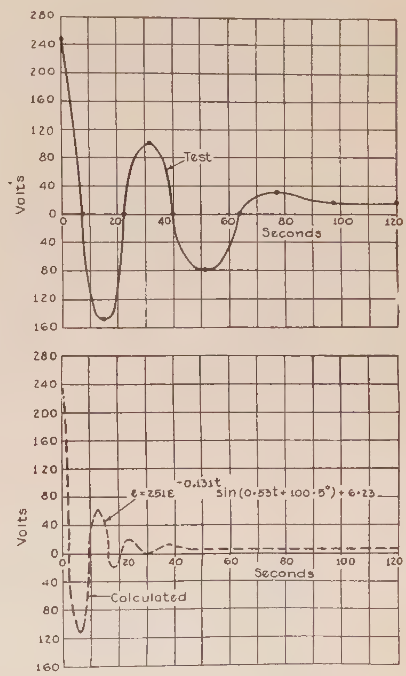

Fig. 7

densities nor does it have a constant intersection e_0 as residual voltage. Hysteresis determines both. However, the curve is *approximately* straight, and the residual *approximately* constant, sufficiently so to warrant the assumption—particularly, since the purpose is not to calculate magnitudes with great accuracy, but only to investigate the character of phenomena and the factors upon which they depend. Thus it will be observed that the tests in this respect compare well with the calculated results. If an oscillation is predicted, it occurs. Its frequency may be different, but it is an oscillation. Just so for logarithmic transients. But in the main, even magnitudes are close.

C. Calculations and Tests

Calculations and tests were made on a 25,000 kv-a. 25-cycle 300-rev. per min. alternator excited by a six-pole compound-wound, interpole, 150-kw., 1200-rev. per min., 250-volt, induction-motor-driven exciter.

Data:[22]

$$
\begin{aligned}
L_1 &= 37.6 \\
L_2 &= 1.69 \\
L_a &= 0.000075 \\
M &= -\ 0.055 \\
k_1 &= 0.805 \\
e_0 &= 5 \\
r_2 &= 0.35 \\
r_1 &= 68.2 \\
r_a &= 0.015 \\
K &= 82.0 \\
k_a &= 0.00125
\end{aligned}
$$

Fig. 5 shows the calculated and test results. With the above constants, γ is imaginary. Hence the cal-

17. Thus Case I, Case II, etc.
18. Case Ia, Case IIa, etc.
19. Except k_a, which was measured.
20. Series field omitted.
21. In direction of rotation.
22. For definition of symbols see "D. NOTATION."

culated curve for current was obtained from equations (**39**) and (**46**); voltage, from (**39**) and (**48**). The test curves are taken from oscillograph records.

Case II. After switch S_1 has been closed and the exciter has built up to permanent condition, S_2 is closed.

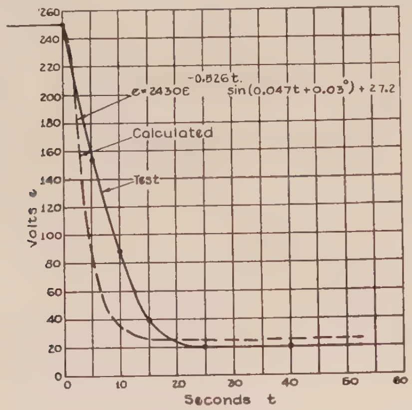

FIG. 8

(a) Shunt exciter with interpoles; brushes two bars forward from neutral.

Data: same as in Case I a.

Fig. 6 shows the results. The calculated curve for current was obtained from equations (**40**) and (**46**); for voltage, from (**40**) and (**48**). The tests curves were taken by stop watch and meter readings.

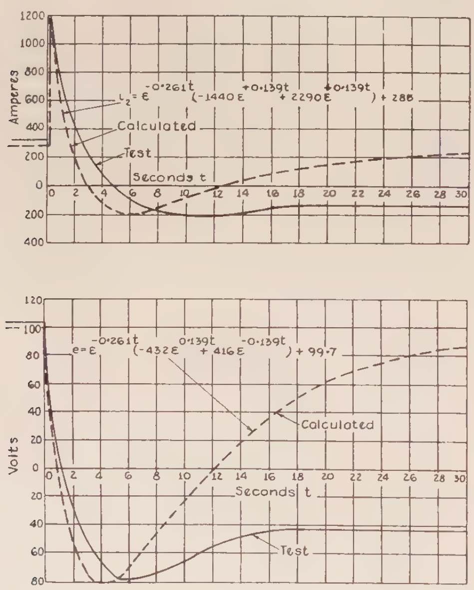

FIG. 9

It will be observed that the current and voltage actually pass through negative values before finally settling at positive values.

(b) Shunt exciter without interpoles; brushes 1/2 bar forward.

Data: Same as in Case Ia, except:

$$k_a = -\ 0.00317$$
$$r_1 = 67.3$$
$$M = -\ 0.142$$
$$r_a = 0.013$$

Fig. 7 shows voltage transient. The calculated curve was obtained from equations (**40**) and (**48**). The test curve was taken by stop watch and meter readings.

It will be observed, as in Case IIa, the voltage passes through negative values before finally settling at positive values. The lower frequency of the test curve as compared to the calculated curve is probably due to slowing up of the transient by hysteresis as explained under "B. Discussion of Assumptions."

(c) Shunt exciter without interpoles; brushes 1/2 bar forward: 1.35 ohms external resistance in the alternator field circuit.

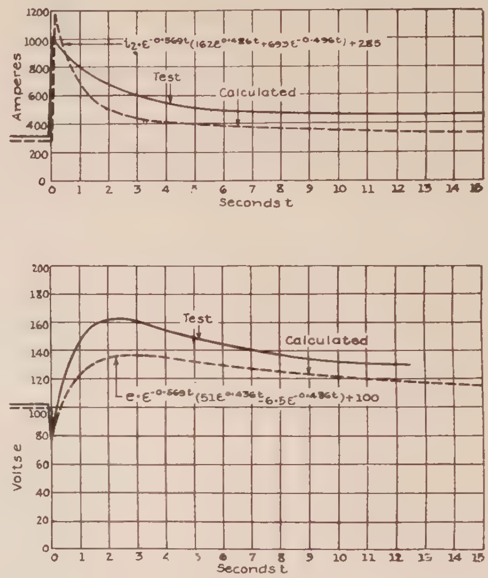

FIG. 10

Data: Same as Case IIb, except, $r_2 = 1.70$.

The voltage transient is given in Fig. 8. The calculated curve was obtained from equations (**40**) and (**48**). The test curve was taken by stop watch and meter readings.

In contrast with Case IIb, it will be observed that the voltage does not oscillate and pass through negative values in going from the one condition to the other. The large increase in alternator field resistance r_2 sufficiently increases the relative magnitude of α with respect to β (see equations (**8**) and (**9**)) to make

$$\gamma = \sqrt{\alpha^1/4 - \beta} \quad \text{real.}$$

Case III. Switches S_1 and S_2 have been closed and currents i_1 and i_2 have reached their permanent values. Alternator suddenly short-circuited.

(a) Shunt exciter with interpoles: brushes two bars forward.

Data: Same as Case Ia except:

$$r_1 = 51.2$$
$$L_2 = L_2' = 0.42$$

Fig. 9 shows the calculated and test results. With the above constants γ is real. Hence the calculated curve for current was obtained from equations (**32**)

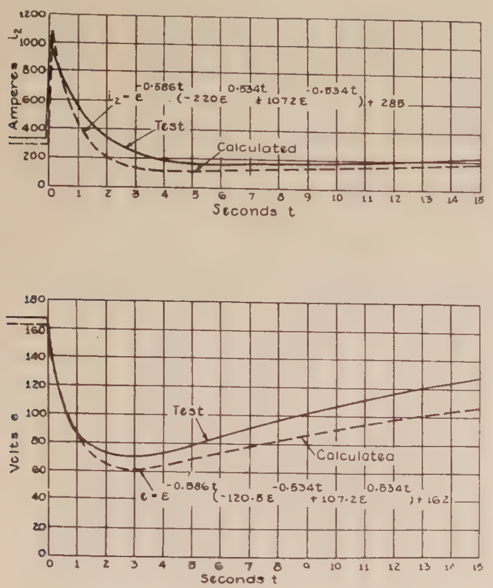

FIG. 11

and (**16**); voltage, from (**32**) and (**47**). The test curves are taken from oscillograph records.

The calculated curves both pass from positive to negative values and return again to positive, whereas the test curves, although following the calculated

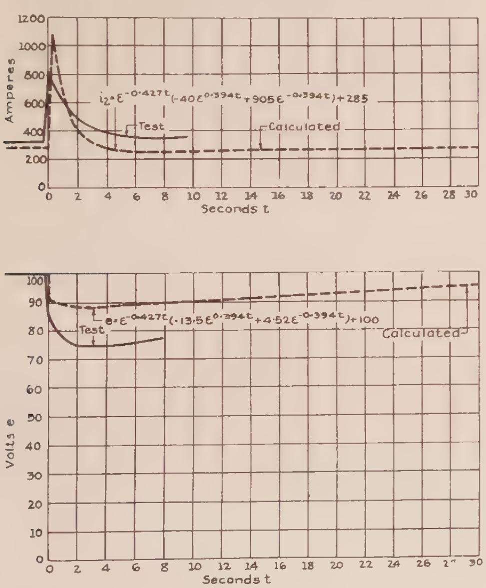

FIG. 12

reasonably close to the maximum negative value, nevertheless do not return to positive values but remain negative. This is explained by the fact that the equation assumes the residual voltage e_0 to be constant and thus always positive. Hence the current and voltage must, by the equation always return to positive values Actually, however, the residual reverses when the voltage and current reverse and hence in this case the test curves remain negative.

If it appeared worth the trouble, the equation could be made to apply by step calculations. That is, a second set of boundary conditions could be taken as those existing at maximum negative e; *i. e.*, at $t = 4$ seconds, Fig. 9, and reversing the sign of e_0.

(b) Compound wound exciter with interpoles; brushes two bars forward.

Data: Same as in Case IIIa except:

$$k_a = +\ 0.00055$$
$$r_1 = 76.2$$
$$r_a = 0.016$$
$$M = +\ 0.0247$$

Calculated and test performance of the exciter is shown in Fig. 10. Thus comparing this with Fig. 9, the addition of the series field prevented decrease of

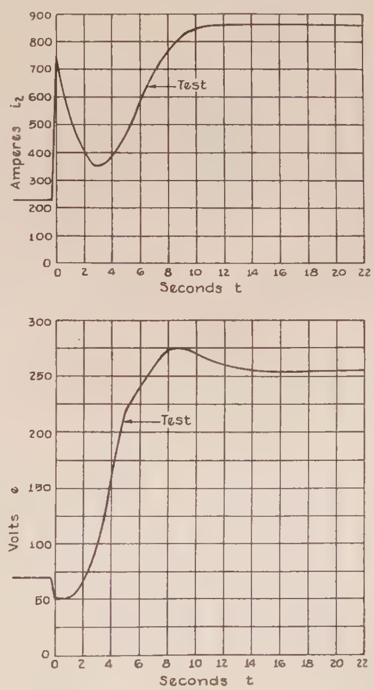

FIG. 13

excitation under the condition of sudden short-circuit of the alternator.

The calculations were made by the same equations as in Case IIIa, and the test curves were taken from oscillograph records.

(c) Shunt exciter with interpoles; brushes two bars forward; 0.22 ohms external resistance in alternator field circuit.

Data: Same as in Case Ia except:

$$r_2 = 0.57$$
$$L_2' = 0.42$$
$$r_1 = 56.0$$

Performance curves in Fig. 11. Calculations from same equations as in IIIa; test curves from oscillograph records.

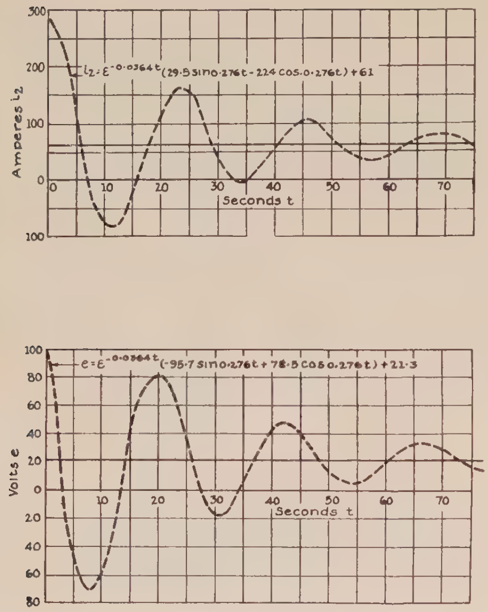

FIG. 14

The alternator field resistance prevented reversal, but permitted the exciting current to decrease to about half the value existing before short circuit.

(d) Shunt exciter with interpoles; brushes one-half bar forward; no external resistance in alternator field circuit.

Data: Same as in IIIa except:

$$L_2' = 0.42$$
$$k_a = 0.00012$$
$$M = -\ 0.0055$$
$$e' = 100$$
$$r_1 = 64.5$$

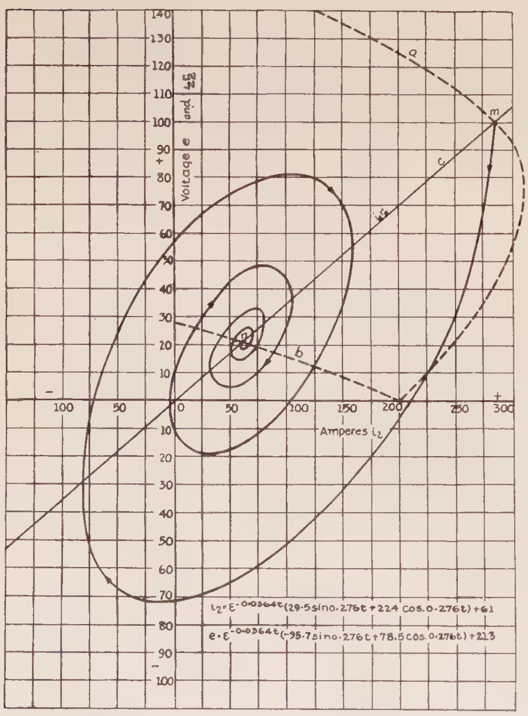

FIG. 15

Fig. 12 shows the exciter to be stable under this condition. That is, with only one-half bar forward shift of brushes from neutral, the droop in the volt-ampere characteristic, as shown in Fig. 4, is not sufficient to cause instability under the conditions of this test.

(e) Shunt exciter with interpoles; brushes two bars forward; automatic voltage regulator; low exciter voltage, to give the least favorable condition for the regulator operation.

No calculations made. Fig. 13 shows the exciter performance under test. The regulator thus prevented decrease in excitation following alternator short-circuit.

Case IV. Switches S_1 and S_2 have been closed and i_1 and i_2 have reached the permanent values i_{11} and i_2'' respectively. The shunt field resistance r_1 is suddenly changed from r_1^0 to r_1'.

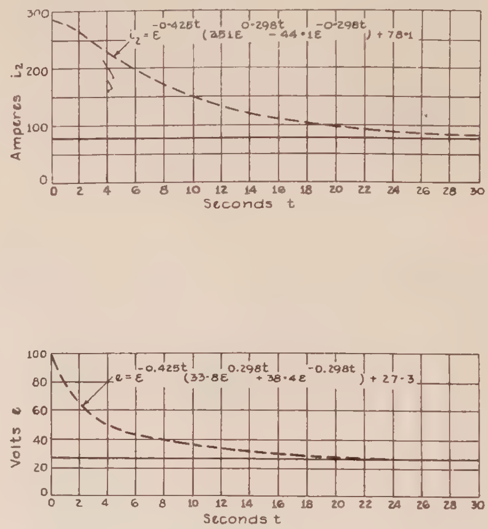

FIG. 16

(a) Shunt exciter with interpoles; brushes two bars forward.

Data: Same as in Case Ia except:

$$r_1 = r_1^0 = 51.2 \text{ before}$$
$$r_1 = r_1' = 60.0 \text{ after.}$$

Calculated curves are shown in Fig. 14. From the above data γ is imaginary. Hence equations (**42**) and (**46**) were applied for current; (**42**) and (**48**) for voltage. This condition gives very long, low-frequency oscillations, similar to Case Ia. Tests were made, and such oscillations were observed, but were not recorded.

These same calculations are plotted in different form in Fig. 15. Here, the exciter voltage is plotted against the current i_2, both being sine functions of time. This makes it possible to show the transient current and voltage in relation to the volt-ampere characteristics a and b of the exciter, and c of the receiving circuit, *i. e.*, alternator field. The volt-ampere characteristic a corresponds to

$$r_1 = r_1^0 = 51.2$$

and b, to

$$r_1 = r_1' = 60.0$$

The curve c corresponds to

$$r_2 = 0.35$$

Before the change the point of operation must be on a and c, thus at m; after, it must ultimately be on b and c, thus at n. The transition is shown by the spiral curve.

(b) compound wound exciter with interpoles; brushes two bars forward.

Data: Same as in Case Ia except:

$$M = + \quad 0.0247$$
$$r_1 = r_1^0 = 76.2 \text{ before}$$
$$r_1 = r_1' = 90.0 \text{ after}$$
$$r_a = \quad 0.016$$
$$k_a = + \quad 0.00055$$

Starting at the same values of exciter voltage and current as in IVa, but now with series field, of course requires higher voltage of r_1.

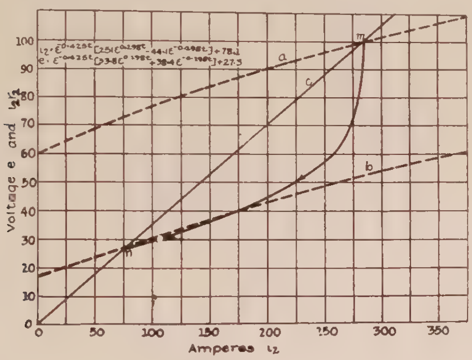

Fig. 17

From this data, γ is real. Hence apply equations (**35**) and (**16**) for current; (**35**) and (**47**) for voltage.

The result is shown in Fig. 16. Thus the series field eliminated the oscillation, giving a gradual decrease of excitation to the new permanent value. As in Case IVa, these data are also plotted in Fig. 17, showing the transient in relation to the volt-ampere characteristics. The curve shows a gradual decrease from the point m on a, to n on b, a and b being the volt-ampere characteristics of the exciter with the series field.

D. Notation

A defined by equation (**10**)

α exponent, defined by equation (**8**)

a, b, c integration constants, defined by equation (**38**)

β coefficient, defined by equation (**9**)

C_1, C_2 integration constants

e exciter terminal voltage

e' exciter terminal voltage at no load

e_a exciter generated voltage

e_0 exciter residual voltage

ϵ 2.718

G $\dfrac{d\, i_2}{d\, t}$, given by equation (**30**)

γ exponent, defined by equation (**14**)

γ' exponent, defined by equation (**36**)

i_1 exciter shunt field current

i_{11} particular value of i_1 in Case III

i_{11}' particular value of i_1, defined by equation (**27**)

i_2 alternator field current

i_2' particular value of i_2, defined by equation (**25**)

i_2'' particular value of i_2, defined by equation (**33**)

i_a exciter armature current

i_0 particular value of i_2, defined by equation (**15**)

j $\sqrt{-1}$

K total generated armature volts per megaline of magnetic flux per pole

k_1 megalines per pole per shunt field ampere

k_a megalines per pole per ampere in the armature circuit. It is thus the net result of the armature, interpole and series field magnetomotive forces, and may therefore be either positive or negative. It is positive if magnetizing, *i. e.* if it adds to the shunt field flux; and negative if demagnetizing

L_1 total inductance (henrys) of shunt field circuit

L_2 total inductance (henrys) of alternator field circuit

L_2' leakage inductance (henrys) between the alternator field and armature circuits, expressed in terms of field circuit

L_a total inductance (henrys) in armature circuit, including the armature and the series and interpole field windings, if any

M mutual inductance (henrys) between shunt and series windings. It includes the mutual inductance of any demagnetizing or magnetizing, armature or interpole turns

m_1, m_2 defined by equations (**12**) and (**13**) respectively

r_1 resistance (ohms) of shunt field circuit

r_1^0 particular value of r_1 in Case IV

r_1' particular value of r_1 in Case IV

r_2 resistance (ohms) of alternator field circuit

r_a ohmic resistance of exciter armature circuit, including series and interpole fields, if any

ϕ magnetic flux per pole in exciter in megalines

θ angle whose tangent is $(-\,b/a)$, equation (**46**)

t time in seconds

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Discussion at Midwinter Convention

HEAT LOSSES IN STRANDED ARMATURE CONDUCTORS*

(Lyon), New York, N. Y., February 17, 1922.

W. V. Lyon (by letter): A series of curves has been plotted which, though they may not be of particular value themselves, indicate a line of investigation that should prove of considerable importance. Curves similar to them have been discussed by Rogowski and others.

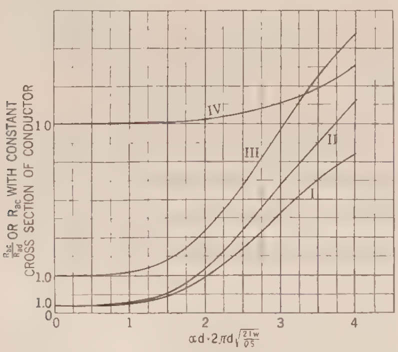

Fig. 1

The curves marked "I" are for the upper bar of a laminated bar winding, with two bars per slot.

The curves marked "II" are the average values for the slot. Laminated conductors with laminations joined at the beginning and end of each turn. Two turns per coil, two coil sides per slot.

The curves marked "III" are the average values for the slot. The winding is exactly like the preceding case but the end connections are turned over.

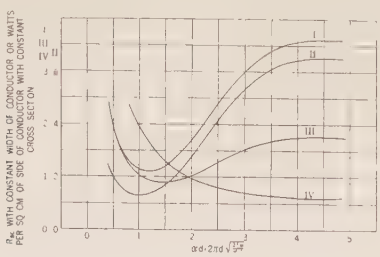

Fig. 2

The curves marked "IV" are the average values for the slot. Laminated coil with laminations joined at the beginning and end of the coil. Two turns per coil, two coil sides per slot. End connections turned over.

All of these curves are plotted for full-pitch, finely laminated windings. The length of the armature core is assumed equal to the length of one end connection. The ordinates of these curves show relative values only. The abscissas, $\alpha\, d$, are roughly equal to the depth of the conductor in centimeters for a frequency of 60 cycles.

Fig. 1 shows how entirely inappropriate laminated bar windings are when the conductors are deeper than about one centimeter. Fig. 2 shows that with conductors of constant width there is a depth which makes the alternating-current resistance a minimum. This has been called the critical depth. Notice that with the better types of windings, viz. III and IV, the critical depth is greater. The ordinates of those curves may also represent the watts per square centimeter of coil side for conductors of constant cross section. If all of the heat developed

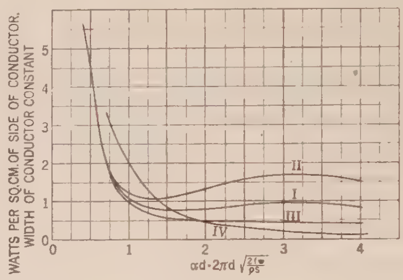

Fig. 3

in the conductors passed through the *sides* of the coil, which of course it does not, these curves would show a truly critical depth.

If the width of the conductor is kept constant the watts per square centimeter of coil side do not reach as distinct a minimum value. In fact in the better windings, III and IV there is no minimum. *i. e.*, critical depth. Fig. 3.

Taking the surface through which the heat is conducted from the coil as the entire perimeter of the cross section of the coil the watts per square centimeter of insulation are plotted in

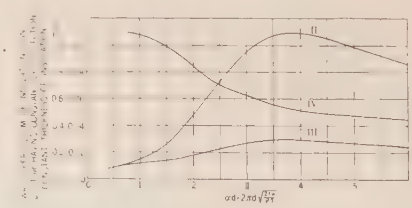

Fig. 4

Fig. 4. These curves were plotted for cases in which the cross section of the conductors was nine square centimeters and the thickness of the insulation was one-half a centimeter.

It seems that these curves only emphasize the need of a thorough investigation of the heat conduction through the insulation of embedded conductors. The problem is further complicated in that the best shape of conductor must be determined by considering not only the heat generated within it but also by the eddy current and hysteresis losses produced in the neighboring iron.

*A. I. E. E. Journal, Vol. XLI, 1922, January, p. 37.

M. S. Vallarta (by letter): Although a few resistance-ratio and temperature measurements have occasionally been reported, no thorough experimental investigation of the Field theory of skin-effect in embedded conductors has to our knowledge ever been undertaken. In order to fill this gap, such an investigation is now in progress at the Research Division of the Electrical Engineering Department, Massachusetts Institute of Technology. Its main purpose is to furnish experimental proof of the correctness of Field's assumptions, since the rest of the theory and its applications, as developed by Rogowski, Richter, Gilman and very recently by Professor Lyon, in his simple method involving the hyperbolic functions of a complex variable, follow from these assumptions by a process of mathematical deduction. Owing to experimental difficulties it has been found necessary, however, to test both the assumptions and the conclusions, as a check on the complete theory.

A piece of standard laminated slotted armature was kindly furnished for these tests by the Westinghouse Company, to which we acknowledge our indebtedness. This is mounted on a wooden framework, away from any magnetic material. So far as the magnetic circuit is concerned, conditions are in close agreement with the ideal demands of the theory.

For the purpose of obtaining the greatest possible resistance, the test coils are made of thin copper strip wound longitudinally in the slots, with its largest dimension parallel to the slot side and with paper-insulated turns. So far as one-dimensional skin-effect is concerned, which is the only one considered in the Field theory, these coils are the exact equivalent of a solid bar conductor of the same dimensions. Stranded conductors with twisted end connections have not been thus far experimentally investigated.

To test the assumption that an element of current in the slot produces no field below it, an exploring coil was placed longitudinally in the slot, with its plane parallel to the slot side, below a current carrying conductor. This exploring coil was connected through a shielded two-step vacuum tube amplifying circuit and thermocouple to a sensitive galvanometer. No deflection could in any case be obtained, thus confirming the assumption. No satisfactory proof of Field's assumption of no component of field strength parallel to the slot side has been found.

An experimental curve of cross-flux distribution was determined by winding five equi-distant exploring coils around the tooth and measuring the voltage induced in them when an alternating current flows through the slot conductors. This voltage was measured by connecting the exploring coils in turn to a sensitive galvanometer through a shielded two-step vacuum tube amplifying circuit and thermocouple. To eliminate tooth-tip leakage, an exploring coil at the top of the slot was always connected in series opposition with the coil through which the flux was measured.

The curve of cross-flux distribution is easily calculated from equation four of Professor Lyon's first paper. The flux linking an exploring coil distance x from the bottom of the upper conductor is

$$\phi_1 = \int_x^d \frac{4\pi l}{s}\left[\int_0^x w\,c\,d\,x + I_2\right] d\,x$$

where $c = f(x)$ is given by the equation quoted above, *i. e.*,

$$c = \alpha/w\left[I_1 \frac{\cosh \alpha x}{\sinh \alpha d} - I_2 \tanh \frac{\alpha d}{2} \cosh \alpha x + I_2 \sinh \alpha x\right]$$

It follows by integration, if $I_1 = I_2 = I$.

$$\phi_1 = \frac{4\pi l I}{\alpha s}\left[\coth \alpha d - \frac{\cosh \alpha x}{\sinh \alpha d} - \tanh \frac{\alpha d}{2}(\cosh \alpha d - \cosh \alpha x) + \sinh \alpha d - \sinh \alpha x\right]$$

For the lower conductor alone:

$$\phi_2 = \int_x^d \frac{4\pi l}{s}\left[\int_0^x w\,c\,d\,x\right] d\,x$$

with

$$c = \frac{\alpha I}{w}\;\frac{\cosh \alpha x}{\sinh \alpha d}$$

whence

$$\phi_2 = \frac{4\pi l I}{\alpha s}\left[\coth \alpha d - \frac{\cosh \alpha x}{\sinh \alpha d}\right]$$

Let ϕ_{10} be the total flux linking an exploring coil at the bottom of the upper conductor. The total flux linking an exploring coil distance x from the bottom of the slot is:

$$\phi = \phi_{10} + \phi_2$$

From which the flux at any point along the lower conductor can be calculated.

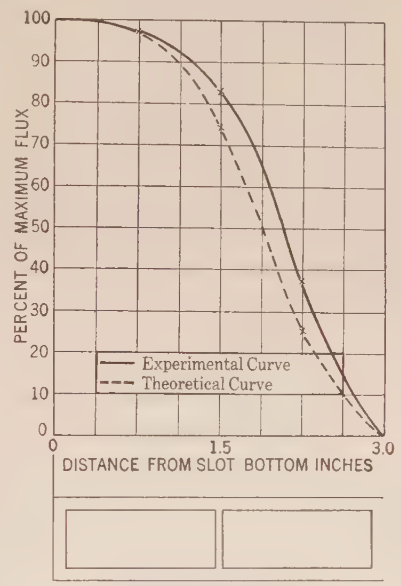

Fig. 5

The experimental and calculated curves of cross-flux distribution are given in Fig. 5. The agreement is considered satisfactory, within the limits of experimental error.

Resistance-ratio measurements have also been made. Power is measured by the three-voltmeter method, especial precautions being taken to have a sinusoidal voltage wave. Oscillographic records show that this condition was in every case closely fulfilled. The disturbing effect of uneven temperature distribution is largely eliminated by operating only after a steady uniform temperature, such as caused by a direct current, has been reached, then making all a-c. measurements within a short interval. To correct for iron loss, a coil of fine magnet wire was wound around the teeth, the excitation being distributed so as to correspond as closely as possible with conditions in the slot conductors. Phase difference effects of course cannot be imitated with this arrangement. The skin effect of such a winding is assumed to be negligible.

Results of resistance-ratio measurements and computation data are given below. Each power measurement given is the average of at least five runs. The precision of individual measurements is estimated at one per cent or better.

COMPUTATION DATA

Dimensions of slot: Width	1.905	cm.
Length	40.6	cm.
Depth	7.62	cm.
Effective width of conductor	1.418	cm.
Effective height of conductor	3.58	cm.
Frequency	60.0	cycles
Temperature	65	deg. cent.

TABLE I

Measured power watts	Measurements for two conductors in series: Current amperes	Correction for end turns watts [1]	Correction for iron loss watts	Net power watts	A-C. resistance ohms
204.9	9.14	3.84	6.05	195.0	2.34
68.0	5.21	1.22	2.21	64.6	2.38
11.53	2.131	0.20	0.50	10.83	2.39
3.32	1.136	0.05	0.22	3.05	2.38
	Average				2.37 ohms
	Embedded portion d-c. resistance				0.2251 ohms
	Resistance ratio				10.52
	Calculated resistance ratio				10.26
	Difference				2.5%

TABLE II [2]

Measured power watts	Measurements for lower conductor: Current amperes	Correction for end turns watts [1]	Correction for iron loss watts	Net power watts	A-C. resistance ohms
95.8	15.16	5.25	3.14	87.4	0.382
34.9	9.16	1.92	1.21	31.7	0.378
11.81	5.32	0.65	0.37	10.79	0.381
1.98	2.21	0.09	0.05	1.84	0.377
	Average				0.3795 ohms
	Embedded portion d-c. resistance				0.1148 ohms
	Resistance ratio				3.30
	Calculated resistance ratio				3.25
	Difference				2.0%

TABLE III [3]

Measured power watts	Measurements for upper conductor: Current amperes	Correction for end turns watts [1]	Correction for iron loss watts	Net power watts	A-C. resistance ohms
181.5	9.36	2.15	2.36	177.0	2.04
62.7	5.47	0.74	1.54	60.4	2.01
10.17	2.145	0.11	0.46	9.60	1.98
2.70	1.140	0.03	0.07	2.60	2.00
	Average				2.01 ohms
	Embedded portion d-c. resistance				0.1110 ohms
	Resistance ratio				18.1
	Calculated resistance ratio				17.27
	Difference				4.8%

1. Length of end turns is 20 per cent of total length. Correction assumes that skin effect in air for the coils is negligible, which is borne out by experiment.
2. Lower conductor alone in slot.
3. Both conductors carrying the same current.

It is seen from the above that, as far as can be judged from our present evidence, the complex hyperbolic method developed by Prof. Lyon correctly describes the cross-flux distribution and gives simple means of computing the resistance ratio of ideal bar windings with engineering accuracy.

In connection with this investigation, the following bibliography has been prepared:

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V. Karapetoff: Prof. Lyon deserves much credit for having worked out in detail various expressions for heat losses in armature conductors, with a non-uniform distribution of current. I wish only to point out some possible improvements in the fundamental mathematical treatment, and to indicate the next steps that might be taken in the solution of this important problem.

1. *Gilman's Work.* In June 1920 Mr. R. E. Gilman presented before the Institute a highly mathematical paper on the same subject (TRANS. Vol 39, p. 997), and it is to be regretted that in Prof. Lyon's paper, presented a year and a half later, before the same body, no attempt is made to correlate his work with that of Gilman's, and to point out identical results, discrepancies, if any, advantages and disadvantages of the two different methods of mathematical analysis. It remains for a future investigator to finish this part of the work.

2. *Exponential Notation.* In my discussion of Gilman's paper (*ibid*, p. 1054) the advantages of exponential notation are pointed out, and it is shown that several pages of long tedious formulas may be done away with, and that a solution of certain simultaneous equations is obviated. It now remains to compare the method of exponential notation with the use of hyperbolic functions of a complex variable, as used in Prof. Lyon's paper. In making this comparison, it is necessary to keep in mind that at the present time we have only Kennelly's tables of such functions, with steps of such magnitude that the two-directional interpolation is quite tedious. The building up of hyperbolic functions of a complex variable out of those of real variables also takes considerable time.

3. *The fundamental differential equation.* The fundamental differential equation of distribution of alternating-current density in a long conductor, subjected to a transverse magnetic flux, is not original either with Mr. Gilman or with Prof. Lyon. See, for example, A. Russell, Alternating Currents, Vol. I, index under "eddy currents." This equation can now be derived much more directly from Heaviside's laws of circuitation which are familiar to the younger generation of engineers. We want as wide a circle of readers for our Institute papers as possible, and any simplification in mathematics, any deduction directly from a general physical law, rather than by a special "follow me" method, is a step in the right direction.

4. *Some mathematical simplifications.* Prof. Lyon's paper being based on a well-known fundamental equation, the value of the contribution lies mainly in the application of the solution to certain specific cases. The solution must be in the simplest possible form for numerical computations. An inspection of his formulas shows the possibility of considerable further simplification. The formulas used in the present paper are based on equation (3) in his first paper (Trans., 1921, Vol. 40, p. 1361). and it is therefore necessary to go back to that paper in order to indicate an alternative treatment.

The objections to Prof. Lyon's formulas are (a) that they are involved and unsymmetrical, and (b) that the variable x enters in the same formula in two or more places. What seems to be a simpler form of solution both for a general development and for numerical work, is indicated below; the equations numbers **1**, **2** and **3**, refer to Lyon's first paper:

Let the general solution of equation (**2**) be written in the form of

$$c = (\alpha/w)\; D \operatorname{Sinh} (\alpha\, y + \beta) \tag{10}$$

This solution differs from equation (**3**) in the following respects: (a) the expression (α/w) is written out explicitly in order to simplify further transformations; (b) the variable distance, y, is assumed to be measured from the center of the conductor, in order to make the equations more symmetrical. In the original paper the corresponding variable, x, is measured from the lower edge; (c) the variable y enters in the equation only once, while equation (**3**) contains x twice; (d) The two constants of integration are D and β, that is, directly the amplitude and the phase, instead of the components A and B.

To determine D and β, we substitute expression (**10**) in equation (**1**), and in the formula for I_1*. After simplification we find:

$$\tanh \beta = [I_1/(I_1 + 2\, I_0)] \quad \operatorname{Coth} \alpha\, d/2 \tag{11}$$

$$D = \frac{1}{2}\, I_1/(\operatorname{Sinh} \beta \operatorname{Sinh} \alpha\, d/2) \tag{12}$$

Equation (**10**), with the auxiliary expressions (**11**) and (**12**) leads to simpler formulas and computations than the formulas used in both of Prof. Lyon's papers. For the current density at the center of the conductor we have, putting $y = 0$,

$$c = (\alpha/w)\; D \operatorname{Sinh} \beta \tag{13}$$

or, substituting for D its value from eq. (**12**),

$$c = \alpha\, I_1/(2\, w \operatorname{Sinh} \alpha\, d/2) \tag{14}$$

which checks with Prof. Lyon's expression.†

5. *Future Work.* There is no reason why this problem should not be brought now to a final solution, at least in application to standard turbo-alternators. By this I mean a set of curves, charts, tables, etc. with which a designer could safely compute the armature copper loss for an assumed arrangement of conductors. At the present stage the designer would have to study one or two highly mathematical articles and then perform rather long computations before he could get a specific result. Should he then decide to change his winding, much of the numerical work would have to be repeated.

*Trans. A. I. E. E., 1921, p. 1369.
†Trans. A. I. E. E., 1921, p. 1372.

Discussion at the Chicago Convention

A RELAY RECORDER FOR REMOTE CONTROL RADIO*

(Dunmore), Chicago, Ill., April 19, 1922.

Wm. McClellan: Is it practical, may I ask, to use that device for the tripping of relays in connection with circuit breakers?

E. E. F. Creighton: I am not sure from the author's remarks whether he used two frequencies, a fundamental and then a note frequency in addition to that, in order to prevent accidental operation. Suppose this device were used to operate a distant oil circuit breaker, what would be the chances of its operating through picking up some wireless wave.

Allan C. Forbes: I think that Mr. Dunmore has a very clever device; the possibilities of which are unlimited, due especially to the fact that it is more compact than any relay that I have yet seen. I happen to have had a great deal of experience in a high power station for the Marconi Company, having done the first testing between San Francisco, Honolulu and Japan; also between Marion, Mass. and Stavanger, Norway, and I have seen a great many recorders, I have worked on them personally and this is the first really successful thing that I have seen that is efficient and yet simple,—plug it into the light socket and let it go.

Mr. Schraeber: The author has explained that you might control a ship or airplane in this way, and he has also explained that he is able to get very close tuning, it being possible to tune both to the audio frequency and to the radio frequency. Having adjusted his device, I would like to know whether he has had any particular experience toward the end of always being able to send out the proper wave, either audio or radio, so that the device in which there is no individual to do the tuning will surely respond to those impulses. Can you set it and leave it perhaps for a day or so at some distant point and then start up a signal which will be closely tuned to it.

Allan C. Forbes: I tried out a device in Bolinas, Cal. (Marion Co.), the 300-kv-a. Radio Station of the M. W. T. Co. of America, while there as dynamo tender, and later on as engineer. We had a schedule of starting up at 10:00 o'clock in the morning to work Honolulu until 2:00 p. m. and then shut down; then start up again maybe at 4:00 or 5:00 o'clock and send what few messages we had. Then we would shut down until 9:00 o'clock at night and then get rid of all the business from 9:00 o'clock until 12:00. This was in 1915-16.

*A. I. E. E. Journal, Vol. XLI, 1922, April, p. 310.

Now there would come long stretches, during good reception, when we could afford to shut down, possibly for an hour. Then the operator would want power quickly. We had induction motors, and all automatic starting; it would take us about sixty seconds to start up. Well, I thought out a great many plans whereby I wouldn't have to get out of my soft box. So I rigged up a relay device, unbeknown to the Marconi Wireless Telegraph Co. of America. I had it fixed so that I kept current on the circuit through the relay, and all the operator had to do was to touch his sending key, that tripped the circuit which threw in the automatic starter and started the main motor-generator set with the main motor generator on the way to going up, all I had to do then was to tell the dynamo tender to start the air compressors and open the valves and we were all ready.

We used a grounded circuit, several amateurs in and around San Rafael had one kw. stations. They were not careful as to their antenna and they used a great deal of power. The relays we used were very sensitive, so much so that one time the whole station was put into operation, and when I got it all going I didn't hear any signaling going over it, so I called up the operator and he said, "No, I didn't ring for the juice." I shut down, and shortly thereafter I started up the same way again. So I disconnected it and sat over by the relays and I could read all the signals that the amateur was sending out from San Rafael. Our line was at right angles to San Rafael, and San Rafael was over twenty miles away. We could have provided against that if we had had Mr. Dunmore's relay with his audio tuning device.

D. D. Clarke: I am connected with an operating company and a device of this kind appeals to us as one that could be put on an auto or truck and enables us to reach the trouble man at all times, without the necessity of his keeping his head set on.

Victor E. Thelin: In connection with the possibilities of this relay controlled by radio, I have been thinking of one thing which no doubt is of interest to you engineers, as many of you no doubt are power engineers, whose work brings you in touch with the furnishing of power from rotary converter and motor-generator substations. Large metropolitan systems, of which the Chicago Surface Lines is typical, heretofore have been fed from multi-unit substations, the capacity of which range from 4000 to as high as 20,000 kw. While complete shutdowns due to trouble on the high-tension system do not happen very often now, due to the fact that practically all of the high-tension lines are equipped with reverse-power relays, which isolate a defective line, yet there are times when quite a number of substations are shut down, and it is necessary, in order to restore service, to open sufficient feeder switches to reduce the load on the feeder bus to the amount capable of being picked up by one rotary, and then as additional rotaries are connected to the station bus more of these feeder switches are closed .

If the large substations in the residential districts and in the outskirts of the city were separated into a number of automatically controlled single-unit substations or, at the most, two-unit substations, it might be possible to have same so arranged that a load despatcher could have complete control of same, through the use of a radio controlled relay which might enable him to connect all of the stations to the system simultaneously. Furthermore, in case of a shutdown on a low-tension d-c. lighting system, such as is used by the Commonwealth Edison Company in Chicago, it is necessary to have a great reserve capacity in storage batteries in order to restore service, as it is impossible without these batteries for any one rotary converter substation to be connected to the distribution system, due to the fact that this distribution system is one solid network, and the first substation in operation would open up on overload. It might be possible to have all the rotaries in both manually and automatically operated substations running ready for service, and the actual connecting of same to the distribution system could be done simultaneously by a load dispatcher through the use of the radio relay described here today. There is one point, however, on which I am not clear, as I have not as yet become a "wireless bug" and that is as to whether or not it would be possible to arrange these relays so that they could be operated independently of all the others in regular service and yet all be closed simultaneously in case necessity so demanded.

H. L. Wallau: There is a possibility of having one or more of these devices to perform different functions in the remotely controlled wireless substation, and I should like to know whether there would be any great difficulty in establishing a code of audio signals that could be easily transmitted from some central point.

F. W. Dunmore: I have, in developing this relay, merely developed it as a mechanism to be operated by radio, having left the finer details of selectivity by means of group signals to someone else who may design a ratchet mechanism that would be operated by this relay. The air service is doing work along this line and has actually obtained results. You have probably read of their radio controlled auto which they have been steering through the streets of Dayton, Ohio, maneuvering it right and left and starting and stopping it and blowing the horn. That has all been done, first, through a relay, and secondly by means of a series of signals properly spaced, and of suitable length, operating a selectivity mechanism, mechanically selective, which, in turn, gives the different controls. These methods for obtaining selectivity, may be used for the control of oil circuit breakers in order to prevent them from being operated by any other signal.

I remember reading recently in one of the radio magazines an article which stated that there had been developed a relay, which performed a similar function to that of mine, but was so fixed mechanically, by certain ratchet mechanism, that it would respond only to three dots, three long dashes, and three more dots (the distress signal). This could be put on a ship without an operator and would ring a bell whenever a ship sent a distress signal.

I cite the above merely to show it is possible to make a relay doubly selective, not only electrically selective by radio, both to radio frequency and audio frequency, but also mechanically selective to the extent that it will not operate a control switch or a signal bell unless a certain number of signals are received in a given time and suitably spaced. A somewhat similar method was used by the air service in the control of the auto in Dayton.

There is another method of obtaining mechanical selective control with which I am familiar, but which I cannot go into now, whereby any number of controls could be made. It is very flexible, making possible 25 or more different controls.

I believe the foregoing will answer the first two questions. In the development of my relay no attempt was made to obtain mechanical selectivity.

As for keeping an enemy from operating the relay, this could be taken care of by the use of a combination of electrical and mechanical selectivity. The code could be deciphered in time but the relay may be constructed so as to operate on a number of different codes.

As for leaving the relay at a substation without an attendant, there is always the danger of a tube burning out, but as the life of a tube is several months, this danger is remote. The control signal could be sent from a given point, and on a given wave length, and be of such character that it would operate the mechanically selective mechanism, which in turn would open or close the circuit breakers.

By utilizing electrical and mechanical selective features, it should be possible to keep an interfering station from operating the relay mechanism.

Regarding the use of the relay on trucks in order to call linemen, it would be simpler to use a radio receiving set without the recorder. This would not require as much mechanism. If the truck were in motion, the relay could be used to make a visual indication or call.

The relay was developed primarily for use on airplanes, and for

this reason was designed to operate on a signal of sufficient strength to give positive action. For use on an airplane a relay should be very rugged and simple, with no delicate adjustments of spring tension and relay contacts or suspending elements. In my type of relay the spring tension can be made considerable, thus pulling the armature back so that vibrations on the plane will not move it until the signal is received. The ignition noise is picked up by the radio receiving set, in some cases just as I received it here from that commutator, and in cases where it is very loud it might operate the recorder. It is possible to shield the ignition systems on airplane engines so as to reduce the noise from the ignition to a minimum. If this interference is not stronger than the received signal, it will not operate the recorder. Thus the relay may be readily used for visual indication on a plane, as the noise is so great from the roar of the engine that it is hard to read a signal by ear.

As for controlling a number of substations by means of one central radio transmitting station, this may be done by sending a signal of a given wave-length and character as I have previously mentioned. Each substation should have a radio receiving set in operation ready to receive the signal. This would mean that the filaments of the tubes would have to be lit, so that the radio receiving set would be ready to function, and thereby operate the relay.

Mr. P. D. Lowell and I have recently developed at the Bureau of Standards a radio receiving set that operates entirely from the a-c. power line. It consists of six stages of amplification. This might be used in conjunction with the recorder on the a-c. supply.

Some very interesting questions have been asked by Mr. Varley of New York, some of which might interest you. He inquired why twenty volts are necessary to reduce the plate current to zero. I am using such a high plate voltage that it requires a large grid voltage to reduce the plate current to zero. Mr. Varley stated that three volts should be sufficient. Three volts would be all right with a plate voltage of 20 volts; I have 200 volts, so I must have a correspondingly higher grid voltage. The use of a-c. does not affect the operation of the recorder. When the relay is adjusted for maximum sensitivity, with a spring tension so that the armature is just about to make contact, there is a slight 60-cycle chatter of the armature but is not objectionable because the relay is never operated in that condition.

Mr. Varley also asks why 4000 ohms were used across the condenser in smoothing out. It should be 40,000 ohms. It serves as a grid leak and keeps the grids from being insulated from the rest of the circuit. A receiving tube cannot be operated with the grids insulated from the filament.

THE ELECTRIC HAMMER[1]

(TROMBETTA), Chicago, Ill., April 19, 1922.

R. E. Hellmund: There is in such a hammer air gaps on the two sides of the moving parts. Have any difficulties been experienced, such as bending of the moving parts, or getting excessive friction on one side?

P. Trombetta: We have not experienced any difficulty in that line, and from the fact that they are pretty well balanced, the difficulties, if there should be any, will be minimized almost to nothing by putting the two stators in parallel, in which case as the air gap increases, the current in the one stator in which the air gap increases must increase, in order to keep the voltage the same, and consequently the force is kept almost constant, and there are no difficulties.

Wm. McClellan: How large a hammer have you built and worked?

P. Trombetta: The total moving mass of the hammer is around 275 to 280 pounds.

H. L. Wallau: What is the force of the blow in foot pounds?

P. Trombetta: That can be easily calculated. When you put full power downwards it reaches a speed of about 13.8 feet per second. That squared, times 275, will give you the force of the blow.

1. A.I.E.E. JOURNAL, Vol. XLI, 1922, April, p. 297.

AIR-BREAK MAGNETIC BLOW-OUTS FOR CONTACTORS AND CIRCUIT BREAKERS, BOTH A-C. D-C. (TRITLE) AND THE EFFECT OF HIGH CURRENTS ON DISCONNECTING SWITCHES WITH SPECIAL REFERENCE TO THE MECHANICAL STRESSES RESULTING[2]

(LOUIS AND SINCLAIR), CHICAGO, ILL., APRIL 20, 1922.

H. D. James: The investigation of basic arc rupturing phenomena is necessary for the proper design of control apparatus. Mr. Tritle in his paper has made a valuable contribution toward our knowledge of this subject. Similar investigations have been made by Messrs. O. H. Escholz and J. W. Legg. The practical results of these investigations are fundamentally the same but different methods have been followed so that the photographs and curves obtained will supplement Mr. Tritle's paper.

Mr. Legg developed a rotary type of high-speed camera which is fully described in the *Electric Journal* of December 1919. This high-speed camera has been found to be exceedingly useful in the study of arc phenomena, particularly in the development of magnetic blow-out switches. Some of the phenomena dis-

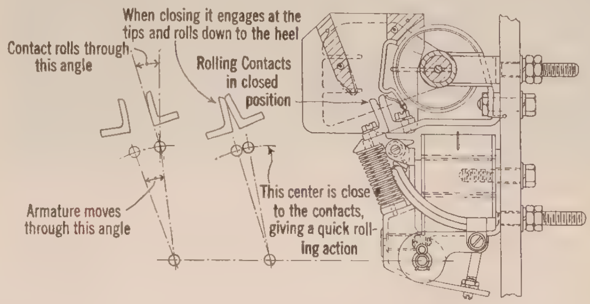


FIG. 1—DRAWING SHOWING ACTION OF ROLLING CONTACTS

closed by its use are discussed by Mr. Escholz in the *Electric World*, September 3, 1921, and were reprinted in leading technical papers including the *E. T. Z.* of February, 1922.

At the annual meeting of the Association of Iron & Steel Electrical Engineers in September 1919 I presented a paper illustrating a line of magnetic contactors embodying improved arc rupturing means resulting from these investigations. This paper was printed in the *Electric Journal* in November 1919 and also in the *Transaction* of the Iron & Steel Electrical Engineers for that year. I will not repeat the details of these papers as they are a matter of record and can be examined by those interested in this branch of the art.

Briefly described, the electric arc is an elastic conductor consisting of a core of ionized gases surrounded by a luminous gaseous envelope. The arc is ruptured by simultaneously lengthening and cooling it. Every arc has a critical length on constant potential systems and will be ruptured if extended beyond this length. This critical length can be decreased by artificial cooling.

Mr. Tritle has brought out the advantages obtained by cooling the arc and a design of contactor utilizing this cooling effect.

Another form of arc box not only cools the arc but confines the critical length within a smaller area of magnetic field. (See Fig. 1).

This is accomplished by an insulated barrier placed transverse to the arc stream causing the arc to form a double loop so that its length is increased more rapidly than if this barrier or splitter were absent.

In addition to stretching or lengthening the arc, this splitter interposes a cooling surface to the arc stream very shortly after the arc has formed. This is the most effective time to begin cooling because of the high energy density per unit length of the

2. A. I. E. E. JOURNAL, Vol. XLI, 1922, April, p. 251 and 267.

arc stream. The arc splitter may have a piece of copper attached to the tip nearest the arc which very materially assists in increasing the cooling. This copper will not form a part of the arc circuit until the two extreme points of the copper shield have become heated to the point where they will emit electrons and ions. By the time this condition has been reached the arc has been stretched to a very considerable length so that its energy density or heating effect is small and in many cases the copper shield is never heated sufficiently to form a terminal point for the arc.

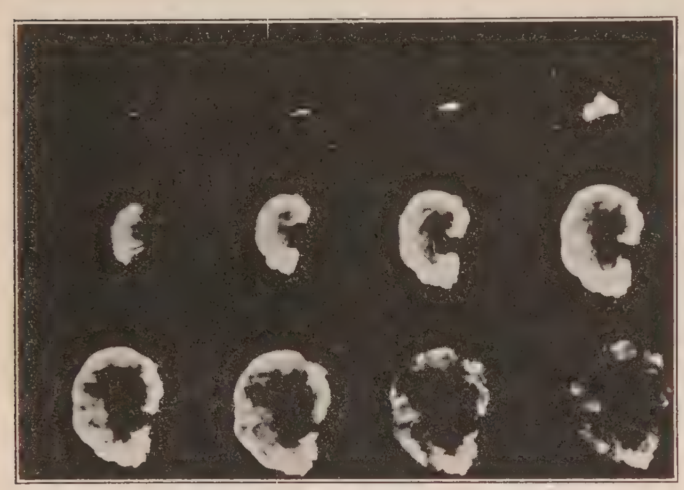


Fig. 2—Variation in Arc Contour on Rupturing. 40 Amperes, 250 Volts, Resistance Load. Max. Length = 20 In., 1600 Exposures per Sec.

If the arc box is enlarged, additional barriers or arc splitters may be introduced. These splitters may have copper shields on the tips if conditions warrant. The small contactors operate satisfactorily without the copper tips and even in large contactors or those used on high voltages only a very few arc splitters require copper shields.

When these arc splitters are properly designed and located they are not subjected to any more burning than other parts of the arc box. Referring to Mr. Tritle's illustration, Fig. 10, it is conceivable that transient parallel arcs may be formed in each compartment, but test data have shown that arcs in parallel

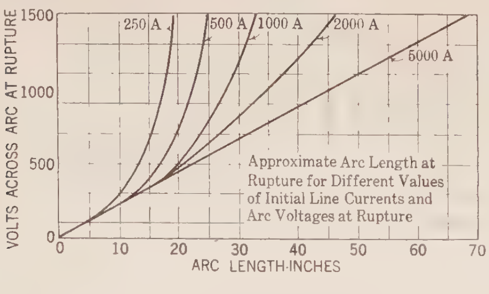


Fig. 3

without individual stabilizing means are exceedingly unstable, and it is to be expected that one of these arcs will be very quickly transferred to the other chamber, thereby reducing the volume efficiency of the arc box.

The dimensions of an arc box are determined by two major factors, the most important being the critical arc length at which rupture occurs and the second the approximate arc width. The critical length of the arc is illustrated by Fig. 3, taken with the high-speed camera. This shows the arc from the time it is first formed until it has reached the critical length where it remains for a short instant and is then ruptured. The critical length of the arcs obtained from test under normal conditions without artificial cooling are shown in Fig. 4 which gives the

Fig. 4—Arc Contour Rupturing 400 Amperes, 250 Volts. Max. Length = 19.5 in., 1600 Exposures per Sec. Note Arc "Splitter"

relation between the volts across the arc at the instant of rupture and the length of arc at that time for various initial line currents. Introducing various cooling agencies will shorten this critical length. Fig. 5 shows the same conditions of ruptures as illustrated in Fig. 3 except with the addition of a barrier transversed to the arc stream. This barrier functions both to cool the arc stream and to cause the formation of a double loop which decreases the area of the arc shield necessary to rupture an arc of a given critical length. An extreme development of the arc splitter is shown in Fig. 6, where three barriers are employed. The illustration at the left shows the arc stream making initial contact with the splitters, and that at the right shows the appear-

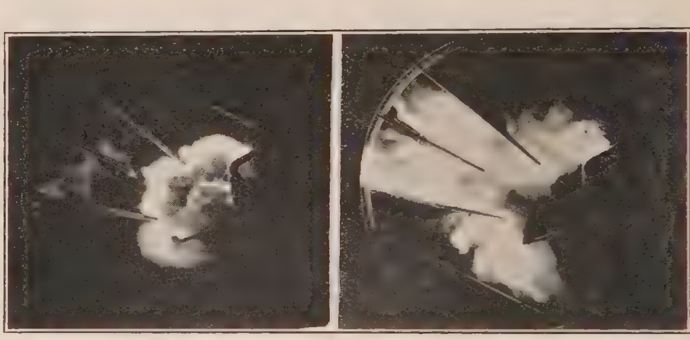
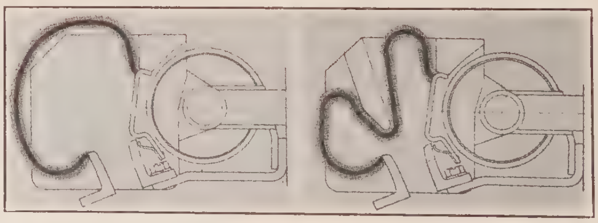


Fig. 5



Without Arc Splitter With Splitter

Fig. 6—Drawing of Contacts and Blow-Out Unit Showing Relative Paths of Arc

ance of the loops immediately prior to rupture. The photograph indicates that the three barriers have not been properly disposed to make the best use of the space. In locating barriers or arc splitters in an arc box, care must be exercised to prevent the retention of incandescent gas and vapor close to the contacts. The effect of such confinement of hot gases can be readily visualized by noting the contour of the incandescent gases in the vicinity of the contacts in this illustration. To minimize the liability of such accumulation of conducting gases it is desirable to provide as free an exit for such gases as possible.

Any restricting means placed in the path of the arc stream will tend to create a back pressure and result in the accumulation of incandescent or conducting gases in the neighborhood of the contacts, therefore, an arc box structure should be proportioned to give ample exit areas. The current density of the arc stream under atmospheric conditions is approximately 500 amperes per sq. in. It is, therefore, evident that if the width of the arc box is less than the normal diameter of the arc stream that this stream will be forced to assume approximately an elliptical shape. This will retard the exit of the arc and its hot gases and augment the accumulation of conducting gases in the vicinity of the contacts.

A B

Fig. 7—A. Example of Contactor without Arc Splitter Opening Circuit under Heavy Ooverload. B. Same Contactor except Equipped with Arc Splitter.

To summarize, the arc is ruptured by stretching to the critical length.

The rupturing capacity of a given arc box is increased by the use of splitters Figs. 6 and 7, due to:

(a) The cooling effect which decreases the critical arc length.

(b) The confinement of a longer arc stream within the available magnetic field.

The box width and position of barriers should be designed to permit the free exit of conducting gases to avoid arc reignition.

B. G. Jamieson: The problem of interrupting a circuit, under load conditions particularly, is of course a difficult one, and the extent to which this air rupturing may be carried is a thing which will interest all of us. Of course, when we think of the application of this principle to indoor work, the first idea that strikes us is, "How much space can we afford the arc after it leaves these chutes, and how much danger is there of re-establishment of the circuit even after the chute has been cleared?" The pictures given by the author mention the arc in one case as 43 x 28 in. If that is symmetrically disposed across three phases it at once brings to our mind the necessity for doing something with these gases after they have left the chute.

In some of the experiences to which the Commonwealth Edison Company have been subjected, the real serious part of the whole affair has been the taking care of the arc after it has left the contacts. A point in that connection which also suggests itself is that there has been a demand created by certain exigencies for circuit breakers, more particularly d-c. perhaps, which will operate within very limited areas or space contents. I was talking with a manufacturer who had been considering the problem of building breakers of the capacity of 1500 amperes, low voltage, and it was necessary to house these breakers, perhaps build them so they could be mounted on 4-in. centers. I asked him if his difficulty lay in the disposal of the arc gases. He told me that much to his surprise the indications were that the disposition of the arc within that enclosed small space was a simple matter, there seemed to be some favorable tendencies of extinguishing the arc, or at least of preventing the re-establishment. So that the point I would like to make is that however efficient this device may be towards the excluding or expulsion of the gases from the point of their origin, to carry this to a successful final usage means perhaps a consideration of the disposal of the gases somewhat beyond the points indicated by the author.

Also there is suggested in this type of circuit rupturing device the question of effect of a passage of those gases past any working parts. I would expect, personally, that there would be considerable damage to parts. Perhaps the design of the breaker takes care of that, but if the breaker is used in a service where it is not convenient to make frequent renewals, it seems to me that more attention perhaps, or more emphasis might have been placed on the adequacy of the breaker with respect to that point.

The paper by Sinclair affords us a somewhat definite measure of the forces and effects operating and produced by certain measured conditions; all operating men have probably experienced some of the untoward results, but they are always at a loss because they don't know, or it is not convenient or easy to determine just what the forces were that produced the results, and that accurate measurement of cause and effect is a very useful step in the determination of the design of apparatus of this sort.

In our own Chicago experience we have had disconnecting switches blow open, not due to the displacement of the blade from the plane of the main conductor alone, but by reason, apparently, of the proximity of other conductors, and there is just a little question whether there isn't a resulting effect which, in the case of three-phase alternating, at least has to be taken into account. Locks have been destroyed when it wasn't possible to account for their destruction by the ordinary explanations given in the paper.

I might add, some years ago, in sort of an experimental attempt, we built some disconnecting switches which were designed to operate directly in the plane of the conductor or rather in the line of the conductor. This switch, if you will imagine a section of a conductor between two insulators removed and a couple of lugs put on the end of those conductors at a distance of 18 inches, and a blade right in the center line of that conductor, you will have an idea of the comparison of the experimental device that we built. We went a little further. We split that blade and we caused it to operate with a scissors-like motion so that the two halves of the blade operating oppositely presented no resultant unbalanced force, so far as the actuation of the device was concerned. Those switches have been in service for some years, and there have been no results, that is to say, no results which would give us any basis for the accuracy of that design. But it would seem as though if we want to get to an easier type of construction, that our difficulty is lessened as we approach the center line of the conductor.

J. B. MacNeill: The theory of the magnetic blow-out is a

proper one to apply to switching equipment of any type where it is desirable to cause maximum extension of arc in a minimum time with consequent reduction in amount of arcing and distress on the switching unit. For high currents considerable blow-out effect can be secured by simple relationships of the current carrying parts and without the addition of blow-out coils.

Such a simple and effective relationship is obtained in the ordinary oil circuit breaker where the contacts into and out of the tank form a loop which gives the positive blow-out effect on heavy currents. On light currents, where the blow-out effect is inadequate for rupturing purposes the addition of blow-out coils and magnetic coils gives the desired result. It may be interesting to note that the Westinghouse Co. has been working for some time on the development of oil immersed switching equipment with magnetic blow-outs to secure high speed rupturing of the arc on comparatively low current. This development will probably be published in the near future.

Air switching using magnetic blow-outs will probably find a serious limitation in difficulties of insulation for high voltages. It would appear that even at voltages of 12,000 to 15,000, the insulation difficulties would become very considerable. This difficulty would, of course be greater for outdoor applications than for indoor. Indoor applications of this principle will find some objection from the noise developed when rupturing an arc unless special provisions are made for reducing the same.

The Louis-Sinclair paper brings out very forcibly some features of past disconnecting switch practise which should be avoided in the future and, therefore, paves the way for improvement in this field which is of considerable importance to operating companies as the concentrations of power become heavier.

Given a lock which performs satisfactorily on short-circuit currents, there is still the hazard that an operator may not completely close a switch in which case the lock does not become effective. In this case poor lock and good lock fare alike as the first short circuit that occurs blows the switch open if of sufficient magnitude. The switch shown in Fig. 22 (page 275) of the April Journal was developed to overcome this difficulty. The relationship of the leads to the switch and the blade is such that if the switch is not completely closed the force generated by the short circuit closes it more completely. A disadvantage of this switch is that the leads to and from it must not be looped in such a way as to neutralize the desired magnetic action.

Switch locks have been developed to overcome the difficulty of an operator not latching the switch. The usual method is to have a lock in which the operator cannot remove the hook stick until the switch has been completely latched. Such devices, however, while they have been on the market for several years have not become widely popular, as they can be fooled by the use of a wrong hook stick.

Supposing lock difficulties have been disposed of, there always remains the possibility with an ordinary hook stick type of switch of an operator pulling the wrong switch with serious consequences. In some of the later high powered stations, therefore, remote control, gang operated switches, operated from the breaker aisle and properly inter-locked with the circuit breaker mechanism have been used. Such switches generally are self-locking by a toggle which goes over center in the closed position. Such switches seem to involve minimum risk to operators and maximum ease and speed in operation. The possibility of trouble with such an arrangement is limited to breakage of remote control linkage which is very remote.

F. C. Hanker: The development of the high speed oil circuit breaker is one which will take care of conditions where we want very high speed of interruption, as is the case in reducing the inductive effect of the short-circuit current. The difficulty we will probably have to overcome will be the minimum current we can interrupt; that is, whether the arc will hang on with small current on account of the difficulty of confining the arc to any specific structure such as a chute. On the high voltage type, to get a material that will stand the high arc temperatures and still confine them is one of the difficult problems.

H. L. Wallau: In connection with the use of locks vs. switches the relative hazard might be illustrated by a practise of our own company in which locks are placed on disconnecting switches which are inserted in the main circuits. The disconnecting switches which are used to cut out potential transformers are not so provided. We have never had any trouble with any of these disconnecting switches on potential transformer circuits, and probably one of the reasons for this is that it is our practise to use a No. 14 varnished cambric conductor to make the connections between the bus and the switch and the switch and the transformer. In every case where there has been any transformer trouble this No. 14 conductor has acted as a fuse, the conductor has usually been completely vaporized simply leaving the enclosing envelope of insulation. No damage whatever has been done either to the switch or the cell structure or anything outside of the particular piece of apparatus in which the fault developed.

H. P. Liversidge: The results which have been presented covering the investigation of the performance of disconnecting switches under high-current stresses bring out some very interesting facts, particularly in reference to the resulting mechanical stresses which are imposed upon the entire switch combination. Certainly the tests made under actual current conditions aid very materially in visualizing actual performance, and it is interesting to note that many of the results obtained check very closely with values obtained by calculation. It is unfortunate, however, that in the combination of the various elements making up the completed switch, further consideration was not given to certain factors which, based on the performance recorded in the paper, must be regarded as variables, and because of this, the results—so far as they apply to separate parts of the combination, can hardly be regarded as conclusive.

It is evident from the report that the high-current tests on switches were instituted with the idea of determining the characteristic performance of switch combinations, as used in one particular system. However, as these tests proceeded, it would appear from the report that the performance of switch combinations taken more or less at random, was used as a basis for establishing the characteristics of various specific designs of switches.

In analyzing any switch test of this nature, consideration must be given to a combination of (a) the switch, including the blade and contacts; (b) the switch lock; (c) insulators with their fittings; and (d) the insulator base.

Since the combination of the different parts making up the switch bears a very definite relation to switch performance under conditions of the character imposed by these tests, it is clear that any conclusions which are drawn as the result of such performance must be based upon a correct knowledge of the design and characteristics of the switch in relation to the duty for which it was intended. It is evident that a light-duty combination which was reinforced by a notched blade so arranged as to act as a tie across the tops of the insulator-supports would show better results than another light-duty combination which was not provided with this reinforcement. On the other hand, a combination of switch, insulator and base designed for high mechanical strains, and of comparatively rigid construction, would, if correctly designed, require no bracing to prevent spreading, and the performance would be largely a question of lock design. Under such conditions, therefore, stresses imposed on various combinations of switch and lock would be largely a matter of resisting the outward thrust of the blade alone.

In looking over the report, it is quite evident that the various switches which were tested showed a random selection of locks, insulators and bases, and in combinations, which, under certain tests, gave rather misleading results. As an example, if switches

reported as Makes *D* and *F* and shown in Figs. 29 and 31, had been mounted on insulators designed for the duty which was imposed upon them, the results so far as the effectiveness of the lock is concerned would, undoubtedly, have been far different. The conclusions which have been drawn by the authors, therefore, and which refer particularly to the operation of switch locks, cannot be regarded as conclusive insofar as the performance of different types of locks is concerned. In commenting upon locks of Make *F*, the authors state that this particular lock proved to be rather inferior and blew open at relatively low currents. An examination of this switch combination would indicate that this type of lock is designed primarily for use on a rigid type of insulating support and base. Where the amount of energy is very limited, a light-duty type of equipment is furnished; and where the forces are heavier, the insulator design and base are proportionately increased, always with a factor of safety sufficient to prevent any movement of the insulators, and, in this manner, positively prevent any relative movement which would affect the operation of the lock. In the particular test cited, a light-duty combination which was not designed for such expulsion forces, was used. While the lock did not open because of any electrical strains, it was forced open by reason of the spreading of the insulators, and the bending of the flat steel plate insulator base. What was actually tested, therefore, was not the lock but the insulators, and this seems to have been the case in quite a few of the tests recorded. On this particular test, the use of the notched blade furnished under certain requirements, in combination with the light-duty insulator, would quite likely have given the true performance of the lock alone.

The writer trusts, therefore, that the authors will continue the work which they have started and inaugurate a second series of tests with the idea of eliminating the variables included in this first series, so that the performance of locks,—which was evidently one of the principal reasons for instituting the tests—may be investigated under the exact conditions for which the combinations have been designed. Unless such tests are carried to a conclusion, it is felt that quite erroneous impressions covering the relative performance of various makes of locks and switch combinations may be secured.

H. B. Dwight: The method of testing disconnecting switches used by Messrs. Louis and Sinclair is very practical and should be of the greatest value in improving the design of such switches. As in the tests made by Mr. Torchio and described in the JOURNAL of the A. I. E. E. of February, 1921, the disconnecting switches were not subjected to a laboratory test, nor to an imitation of operating conditions, but they were made to carry actual full-size short-circuit currents from large generators. Since the most exacting duty required of disconnecting switches is to carry short-circuit currents, weaknesses or improvements in design disclosed by such tests may be trusted in forming a judgment of the relative value of different designs.

While the final criterion of the value of a design of a disconnecting switch is its performance under actual short-circuit conditions, calculated values of forces are useful in correlating test results, and in pre-determining the operation of the switch when it is not practicable to make full size tests. This is also true of the effect of the neighboring parts of the circuit, one or two cases of which were tested by Messrs. Louis and Sinclair. Many different forms of circuit may arise in practise, and comparisons between them can usually be made by calculation, using the methods, and in many cases the partial formulas, of the complete paper by the writer in the 1920 TRANSACTIONS.

These methods of calculation and partial formulas can be used also for calculating the force at each point of the switch supports, tending to move the insulators apart in a direction parallel to the switch blade, as described by Messrs. Louis and Sinclair.

The comparison between the measured force and the calculated force given in connection with Fig. 6, by which they differ by 11 per cent shows very satisfactory agreement between test and calculation, considering the nature of the test measurement and of the problem calculated. While the currents in the parallel parts of the jaw would tend to squeeze the jaws together and increase the friction, the explosive action of metal vapor or oil vapor in the jaw would tend to decrease the friction, even if it did not force the jaws apart as in Fig. 4. The authors state that "in most cases when the switch blew open the break jaws spread apart." It would be expected that this action would be more pronounced when a lock is used, since heavier currents would flow at the time of opening than would flow if no lock were used.

H. R. Woodrow: The paper by Messrs. Louis and Sinclair bring out two points which I would like to emphasize. One is the effect of the circuit external to the disconnecting switch on the electromagnetic forces on the disconnecting switch. It is therefore, of paramount importance that the operating engineer or the consulting engineer take into account the conductors leading away from or in proximity to the disconnecting switch, in determining the forces on the switches.

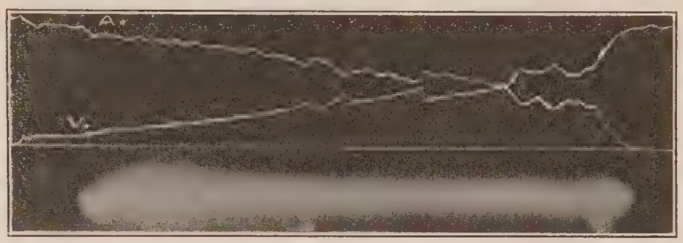


FIG. 8—RECORD OF CHANGE IN ARC DIAMETER, ARC VOLTAGE, ARC CURRENT, ON RUPTURING 260 AMPERES, 250 VOLTS. VERTICAL CARBON ELECTRODES.

The second feature is pulling stresses produced at the clips of the disconnecting switch, which tend to pull the switch in two. This makes it desirable to have the locking device constructed in such a way as to counteract the forces produced in line with the switch, as well as the opening force.

J. C. Bank: I would like to ask Mr. Tritle what the chances are of developing his switches for out-door use? I am afraid that many of the operators will be somewhat hesitant about putting switches which produce large arcs indoors at the stations, but if they could be put outside, where more space would be available, it would be a very valuable feature.

O. H. Eschholz: Mr. James has referred to two important characteristics of the arc during the period of rupture, *i. e.* the critical or unstable arc length and the area of cross section of arc stream, that merit further comment.

The critical arc length on rupturing a direct current supplying energy to a resistance load is a function of the line current as well as of the voltage at rupture. For large initial current values it may be computed by assuming one inch length per 22 volts of the line or surge voltage. With the critical length of arc approximated, the contour of the magnetic field may be chosen to assure the application of a positive directional force on the arc stream until rupture occurs.

The selection of arc chute width, location of splitters or barriers and method of breaker ventilation, are determined chiefly by the area of the arc stream section. A narrow arc chute and improper barrier positioning may result in rapid switch depreciation, noisy break and excessive arc duration due to arc reignitions resulting from the trapping of large incandescent gaseous masses near the breaker contacts.

Although the exact determination of the arc stream section is not necessary, some conception of its order of magnitude is essential. Through the use of an ingenious optical system

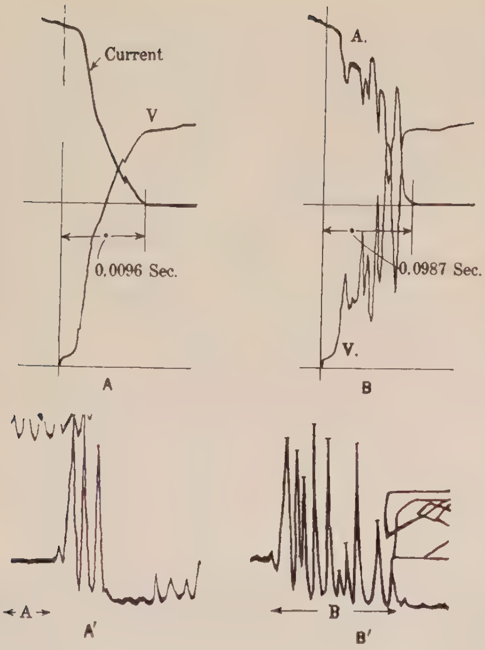


Fig. 9—Variation in Arc Current, Arc Voltage and Arc Noise on Rupturing 500 Amperes, 600 Volts, Resistance Load, in a Magnetic Blowout Field.

A and *A*—Arc passing through center of arc box.

B and *B*—Arc impinging against wall of arc box.

The switch noise intensity was approximately recorded by securing the oscillographic record of resistance variation in a granular-carbon type of telephone transmitter, upon the impact of sound waves. It will be noted that the current and voltage changes in *A* are quite regular, while in *B* both oscillate at moderately high frequencies. These oscillations produced a ripping or tearing noise in *B* having a higher intensity and pitch than the more muffled sound in *A*.

devised by J. W. Legg, simultaneous records of arc voltage, arc current, and approximate arc width, as shown in Fig. 8. were secured. Although the sensitized film is affected by both the wave length and intensity of the radiated energy, it was possible, by the inspection of numerous films, and the known the incandescent gases near the contacts, on arc rupture characteristics is shown in Figs. 9 and 10. For most purposes it was found convenient to determine the arc core section by assuming a current density of 600 amperes per square inch and an envelope thickness varying from ¼ in. to ½ in. depending upon the magnitude of the initial current and the applied voltage.

With the development of similar fundamental data and knowledge of operating principles, it has been found possible to extend the field as well as to place the design of magnetic blowout breakers on a similar plane with that of other electrical apparatus. I am therefore in hearty accord with Mr. Tritle's conclusions that the limiting values of current and voltage that may be successfully ruptured in air have not been reached by service requirements.

J. F. Tritle: I wish to thank Mr. James for his very excellent contributions to the subject, having in mind particularly Mr. Jamieson's remarks on the desirability of rupturing these arcs in the smallest possible space. It seems to me that any device or combination of devices which helps in doing this materially advances the art.

The arc barrier placed transverse to the arc stream, described by Mr. James, certainly cuts down the amount of vapor, and increases the rupturing capacity of a given design. We also made tests on arc barriers of this kind and our results more or less checked Mr. James' results. However, when rupturing high power circuits at 600, 1500, 3000 and 6000 volts we obtained materially better results from the arc suppressor plates; which split the arc into a plurality of multiple connected paths.

Of course, the number of arc suppressor plates and the width of the slots must be properly proportioned for each particular design so as to provide for the exit of the maximum arc with the attending hot gases. We consider it an advantage to have the width of the arc box or the slots less than the normal diameter of the arc stream, as this arrangement forces the arc stream to take an elliptical shape, thus giving the maximum area in contact with the arc chute sides for cooling effect.

Our tests indicate, that as the normal cross section of the arc stream is reduced the arc resistance is increased and therefore the critical arc length is reduced. When the arc suppressor plates and narrow slots are used, we can assume in excess of 40 volts per inch length of arc rather than the figure of 22 volts mentioned by Mr. Escholz.

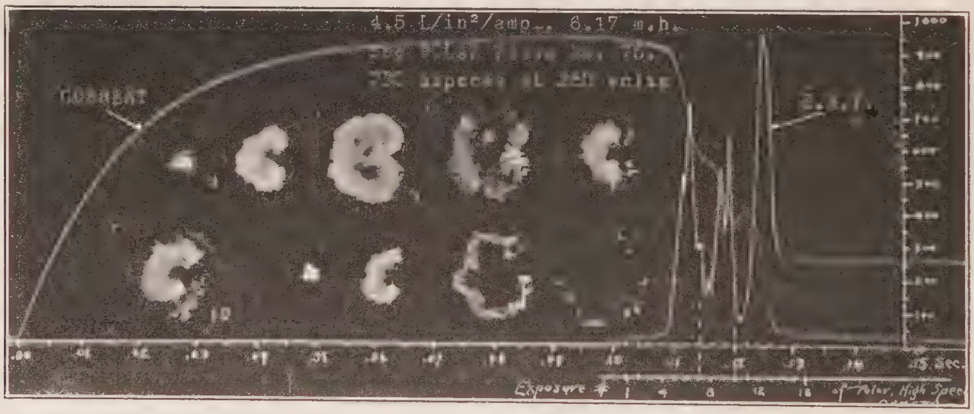


Fig. 10—Arc Re-Ignitions

Arc rupture characteristics of an experimental switch under conditions causing pocketing of incandescent, conducting gases in region of contacts. Note arc stream development and the two subsequent arc re-ignitions at the contacts shown both in the oscillographic and photographic records.

performance of various structures, to arrive at a working value of arc stream diameter. This was found to be roughly in inches, $D = 2\,t + 0.046\,\sqrt{I}$, where t is the thickness of arc envelope in inches and I the initial line current.

The effect of employing too narrow an arc box, or of confining

Regarding the instability of the transient parallel arcs illustrated in Fig. 10 of the paper, it is true that these arcs are very unstable, but photographs taken looking into all the slots distinctly show the hot vapors coming out of all of them, particularly when rupturing heavy currents. We have not been able

to measure the exact distribution of current, and it is probable that the final rupture of the circuit takes place in one slot. The other slots and suppressor plates, however, are effective in absorbing energy from the circuit when the arc stream current is the highest.

Mr. Jamieson commented on the space required for rupturing the circuit with this air break device. I agree that the amount of space, 43 by 28 inches, appears rather large. However, this particular contactor was really designed for a lower voltage. That is, when we started out we had in mind rupturing only about 2500 volts, and something like 1500 to 2000 amperes. As the tests developed, we found we were able to rupture a great deal more power than that. If the arc chute had been designed especially for the higher voltage and current, the amount of vapor outside of the arc chute could have been very materially decreased. Fig. 24 is more nearly illustrative of normal conditions. In this test 5000 volts and 2300 amperes were ruptured, and the luminous vapors came out only four inches. In addition, it is possible to put covers over the front of the arc chute so as to direct the vapors. For instance, on a three-phase circuit you can direct the vapors from one phase up, the second phase out and the third phase down so as to practically eliminate the danger of short circuits between phases. Regarding the effect of the passage of the gases through the arc chute. It is quite possible to design both the arcing horns and the arc chutes side to have a very long life. The arc is moved through the arc chute so quickly that it doesn't have time to rapidly erode or burn away any one particular spot. One of the outstanding advantages of the air break contactor is the large number of short circuits or heavy currents which may be successively ruptured without attention to the arc chutes and current carrying parts.

Mr. Trombetta asked about the progress of development work to decrease the amount of gases. The arc suppressor plates, arc barriers and the arrangement described by Mr. Creighton are the most effective means that I know of.

Regarding the effect of inductance and speed of rupture on the length of the arc, inductance increases the arc voltage, so that necessarily in rupturing an inductive circuit a much longer arc results than from a non inductive circuit. I don't know that there is any particular relation between speed of rupture and arc length.

Mr. Bank inquired about the chances for outdoor installations. The type of contactor described has all the parts exposed, and for outdoor service it would be necessary to provide a switch house or enclosure to protect it against the weather.

The design shown in Fig. 14, is arranged for both cam operation and for remote control by means of a solenoid so that it would be suitable for this kind of an installation or for mounting on galleries in the main station at a distance from the operator.

C. T. Sinclair: We realize the short-comings and incompleteness of our tests, particularly with regard to the effect of return conductors on adjacent switches carrying short-circuit currents. For example, our tests in only one or two instances were concerned with the effect of an adjacent conductor, as explained in the description relative to Fig. 5. But where we have three disconnecting switches located in compartments relatively close together, it is evident that a short circuit between phases will produce forces, as Mr. Woodrow and Mr. Jamieson brought out, on the other switches which will mutually react on one another. The nature of the short circuit will determine the phase displacement of the several currents involved and consequently any calculation would have to take this displacement into consideration.

I was very much interested in the switch described by Mr. Jamieson which is apparently very similar in pricinple to Mr. Rickett's switch; that is, a switch in which the current passes straight through the conducting elements. In Fig. 32 in the paper is shown a cam lock switch which was designed by F. T. Leilich of Baltimore. This switch was constructed partially to take care of the difficulty as outlined by Mr. MacNeill, that the operator might not close the switch far enough to cause it to lock; in case this switch is even partially closed the cam lock will hold effectively. The tests on this switch are unfortunately, not complete.

Regarding the criticism of Mr. Liversidge, I would like to say this: that the authors attempted to bring out these very points in this paper, that the *combination* of lock, switch and insulators is of paramount importance. This is simply another illustration of the fact that a chain is no stronger than its weakest link, and apparently in the switch referred to by Mr. Liversidge, the weakest link is in the insulator and mounting. I assume the reference is to Fig. 31, which is a switch that was submitted to us for test by a manufacturer. We requested that the manufacturer send us a switch with *heavy duty insulators*. Not being familiar with this particular manufacturer's design, we could only assume that we had received the switch with insulators as requested by us and as specified by them.

H. C. Louis: I would like to accentuate the fact that it is not our intention in this paper to criticise for the sake of condemnation any particular designs or makes of disconnecting switches but to impress on manufacturers and operating companies the importance of understanding and taking care of the various factors involved. Mr. Liversidge in his discussion has stated that the performance under our tests of a certain lock was not due to the design of the lock itself but to other circumstances. This is another example of the necessity of considering all factors involved, which as an operating man, I can appreciate very much.

A piece of apparatus is installed, designed and expected to do certain things; it fails to do so, perhaps due to secondary effects, not previously realized; the operating company suffers severe inconveniences and losses, and the manufacturer may be compelled to change it. So, therefore, it seems that if such facts as are brought out in this paper are not taken as merely adverse criticism but as an intended help, for all concerned, both manfacturer and user will be benefited.

SELECTION OF ELECTRICAL APPARATUS FOR CRANES (McLain) AUXILIARY ELECTRICAL EQUIPMENT FOR MOTOR-OPERATED CRANES (Eastwood), and ELECTRIC CRANE CONTROLLERS*

(Schnabel), Chicago, Ill., April 21, 1921.

C. A. Bird: Referring particularly to Mr. Eastwood's paper on brakes, we might add the subject of weather-proof coils. Cranes at steel mills usually are used out of doors, and are subjected to weather conditions that are rather severe, and the design of the brake might be well considered along the same lines as those of the motor. This will refer to the linings as well.

On the limit switches, I have seen a lot of well-known 2 by 4 type short-circuit in the armatures and reduce the efficiency of the motor.

I cannot understand why the dynamic braking type is not used more than it is. It is certainly a device that will give the protection that is desired on crane hoists.

On crane protecting panels, there is no question but that they are being used more and more. They provide a very convenient means of combining all the devices for protection of cranes all in one unit. The practise now is to enclose the steel panels in a steel cabinet and lock it so the operator cannot interfere with the setting of the relay.

H. D. James: Mr. Eastwood states: "It is difficult to secure more than a 65 per cent speed reduction when lowering a heavy load without dangerously overloading the field windings." These data seem to be based on the assumption that in dynamic brake lowering not more than full-load current can be passed through the fields. Well designed motors will stand more cur-

*A. I. E. E., Journal, Vol. XLI, 1922, March, p. 240 and April pp. 313 and 319.

rent than this and in many cases 150 per cent full load may be used. The minimum speed obtained with any particular motor depends upon the combined design of the motor and controller. Where low speed is an important factor, it is very desirable for the engineers designing the control to work in close contact with the motor designers in order to obtain the best results.

Under the head of A-C. Magnetic Friction Brakes, the assumption is made that the lowering speed under load will not materially exceed the synchronous speed of the motor. This assumption is true only when the secondary of the motor is short-circuited. Much higher speeds can be obtained with resistance in the secondary if a load brake is not used. For ordinary shop cranes the most common and perhaps the best practise at the present time is to use a load brake.

Dynamic braking for a-c. hoist motors may be obtained in any of four ways: (a) Exciting the stator with d-c. power; (b) Using a two-speed motor; (c) Plugging the motor in the reverse direction with resistance in the secondary for varying the slip; (d) The use of a frequency changer in the primary.

All four of these methods are in successful operation but are not ordinarily applied to cranes.

The d-c. system of dynamic braking provides for motor operation at low speeds where power is required to lower the hook. As soon as the load changes from positive to negative, the motor speeds up and the braking operation automatically takes place without changing the motor connections. This arrangement permits the gradual lowering of the hook under all conditions of load. When a-c. motors are used the use of d-c. power in the field or of plugging the motor does not provide for the gradual lowering of the hook without changing the motor connections. The two-speed motor might be designed to give the desired minimum speed on the low-speed connection but ordinarily this connection gives too high a hook speed. The use of a frequency changer in the primary will give the desired low hook speed but involves additional machinery on the crane. In view of these limitations the load brake seems to be the most desirable practise at the present time.

I agree with the author that every crane should be equipped with a limit switch that opens the main motor circuit at the upper limit of travel and is operated by the block or hook. In many cases the head room under the crane is so limited that it is difficult to avoid running into the limit switch and I see no reason why this switch should not be designed in as durable a manner as the other portions of the control equipment so that it will withstand repeated operation.

I do not believe that the design should be arranged to cause inconvenience to the operator in resetting this switch, particularly where the head room of the crane is limited. We have crane equipments in our own factory where the limit switch must be operated on nearly every hoist motion. This is an extreme case but there are many other applications requiring the frequent operation of the limit switch. If we require the trolley to be run over to the cab in order that the operator may reset the limit switch we impose a hardship and where this operation has to be performed with a heavy load on the hook we may introduce a hazard out of proportion to the results obtained.

Elevators and other hoist devices similar to cranes are provided with a durable limit switch which may be operated every time the car reaches either limit of travel.

It seems to me that in condemning the use of springs the author is condemning all control apparatus. I do not know of any normal design of control where springs are not relied upon for maintaining contact pressure between the current carrying elements of the switching mechanism. A failure of these springs might result in serious accidents. The reliable operation of control apparatus is a proof that springs when properly designed are reliable. There is no mystery about the proper design of springs. They are composed of the same kind of material we are accustomed to using in other parts of the design and under other conditions. It is well known that if the fiber stress in the metal, whether it is a spring or some other part of the apparatus, is in excess of a safe limit that breakage may result. The spring failures can usually be traced to improper design. A great many springs are not accurately calculated but are the result of a cut-and-dried process. The calculations of a spring are more difficult than an ordinary beam and some designers have not had the necessary experience to properly determine their fiber stress.

I am a strong advocate of the use of springs instead of gravity as they have very little inertia, are compact and can be worked into a design to much better advantage. They are not affected by vibration. The magnet brakes we use for holding crane loads are set by springs. Why discriminate against the use of a spring as the actuating means of a limit switch when we use springs in the current carrying parts of this limit switch and we use springs for setting the magnet brake which is operated by the limit switch and use springs in all other portions of the equipment including the motor brushes which form part of the dynamic brake circuit? I do not feel that I can express myself too strongly on this point.

P. Trombetta: I don't quite agree with the gentleman that just spoke in that a spring is like a beam. The making of a beam does not involve the process of hardening and proportioning the carbon, etc., while making a spring is almost a matter of art. There are only certain companies that make springs, and sometimes you cannot even rely on those springs. I know of an instance where a company tried to make springs by themselves for use in a certain truck; they tried for several years, and so far as I know, never succeeded in making two springs alike. Probably every one of them gave trouble when they were in use, and I can't see how the spring may be compared with a beam. I must agree with him, however, that perhaps too little attention is given to their design, and also that the spring in a good many cases is the only solution of the problem, because it does not introduce additional masses which have to be accelerated whereas balancing by gravity, by eliminating one difficulty, we insert another, which is inertia, and you often find that the cure is worse than the disease, and consequently we may state that the spring has certain places as well as gravity has certain places in engineering and there are certain applications where only gravity can be used, for instance, in elevators, springs would be the best thing there is for such services, but we can't hope to find a spring that would be as long as an elevator shaft. It must be understood however, even elevator balancing weights are very detrimental since they must be accelerated and retarded just as the elevator itself.

Albert J. Acker: Mr. Eastwood made a statement that a band brake doesn't exert a braking torque in the hoisting direction, that is, with the motor armature operating in the hoisting direction. That is true if the band is anchored at one end only, but it is possible to make a band brake with both ends attached to the lever and have it exert equal torque in both directions, and therefore stop the motor just as promptly when it is revolving in the hoisting direction as it does in the lowering direction. A further advantage in such an arrangement is that the same band can be put on the intermediate shaft brake or the second shaft brake, and anchored at one end and give interchangeable brake parts for both of those brakes.

About limit stops, Mr. Bird stated that he couldn't understand why the dynamic braking limit switch is not more widely used than it is. I think I can answer that question. The reason is because there are so many varieties of cranes, so many different numbers of parts of rope, two parts, four, six, eight, ten parts, and all the different styles of lowering blocks, and it is difficult to put on those dynamic braking limit stops in many cranes. That is, to find the room to put them. In two respects, it is difficult to find a place to put them on the trolley itself, and it is difficult to hang the operating or tripping mechanism above the lowering block.

Another difficulty with limit switches is that the crane hoist is so frequently used for something else besides hoisting; to pull a car or to drag something along the ground, and the rope is pulled off at a sharp angle, and any mechanism that is put above the lowering block is likely to be bent or broken when the crane is used in these unusual ways. You all know that that is done very frequently. In an attempt to make a limit switch that could be tripped by the lowering block and yet not be rigid, so when the rope is pulled off at an angle it won't break, the scheme of using a mercury tube has been tried, the idea originating from its application to rubber calendar work. You may know that a rubber calender is very dangerous to operate and there is usually a board across for a man to butt his head into for a quick stop if he catches his hands. This board trips a switch of some kind. Mercury switches have been used for that purpose, a little tube no larger than a 30-ampere fuse with contacts arranged in it, and a little puddle of mercury. If it is tipped one way it makes a contact, and if tipped the other way it breaks it. That same tube applied to a crane limit switch works out well in many instances. It can be put in a little box with an arm sticking out from it and hung so the lower block coming up must tilt that lever arm. Now that can be hung perfectly free and no matter how the ropes pull off, it cannot be bent or broken, yet when the lowering block comes up and tilts it, it will trip the limit switch. Of course that will have to operate on control circuits, not on the main circuits. For some cranes this is a valuable idea, because it is so difficult to bend or break.

It is possible to get on the market now a tube filled with inert gas so the contacts don't blacken after many makes and breaks.

MAGNETIC FLUX DISTRIBUTION IN TRANSFORMERS*

(McEachron), Chicago, Ill., April 19, 1922.

R. E. Hellmund: The points brought out in the paper simply emphasize something which is overlooked too much in teaching. In electrical engineering, we frequently cannot see the real thing and are forced to adopt conventions in order to make things clear with our limited mental facilities. Now, as long as we have to adopt conventions, we are perfectly at liberty to adopt the one or the other, but the thing that is neglected is to make it perfectly clear that we are dealing with conventions instead of facts. It is all right to teach the separate fluxes to the students, but we must keep in mind that in doing so we are adopting conventions and that the actual resultant fluxes may be different as shown in the paper.

This same point has been discussed for many years, especially in connection with induction motors, where similar problems arise. For instance, if we have induction motor slots (A) and (C) as shown in Fig. 1, we can represent the main flux by lines (b), the primary leakage fluxes by lines (a), and the secondary leakage fluxes by (c). Now if we assume the extreme case of standstill and zero resistance in the secondary squirrel-cage winding, we know that the resultant flux entering a secondary tooth must be zero; in other words, the secondary leakage flux (c) must be equal and opposite to the main flux (b). It follows, therefore, that as a matter of fact we do not have separate fluxes (b and c), but a flux (d) which flows around the primary slot, across the air gap, and across the secondary slot opening; in other words, we have here a condition in an induction motor similar to those discussed in the paper for a transformer. Here it is again convenient to adopt conventions dealing with separate main and secondary leakage fluxes, while as a matter of fact, the real fluxes are entirely different. There is no harm in adopting the convention so long as it is made clear that we are dealing with conventions, not actual facts.

Another similar case is the so-called zigzag leakage in induction motors, which is frequently illustrated by a flux line (a) as shown in Fig. 2. We have, of course, in addition to the leakage fluxes, the main flux lines (b). It is at once evident in this figure that we will not actually have in the air gap portions (P_2) certain fluxes (a) flowing in one direction and another flux (b) flowing in the opposite direction, but that we actually have a resultant flux density in the gap portions (P_2) which is the difference between the fluxes (a) and (b). In other words, the zigzag leakage fluxes merely weaken the field in the gap portions (P_2). Similarly, it is evident that the leakage fluxes (a) strengthen the flux in the air gap portions (P_1). It is, however, practically impossible for us to work up theories taking into account the effect of the leakage fluxes along the actual line of weakening the main flux in certain portions of the gap

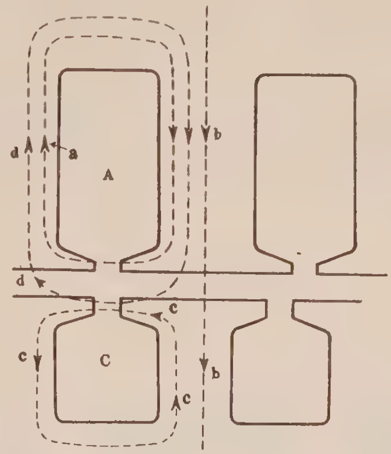


Fig. 1

and strengthening it in others; while, if we adopt the convention of separate fluxes, the desired result is obtained without much difficulty.

An exception to the more usual cases, where the leakage fluxes do not actually exist in line with the adopted conventions, is found in the end connection leakage of induction motors. Fig. 3 shows primary core (D) and secondary core (F), with coil windings in the primary and squirrel-cage windings in the secondary. The main flux is illustrated by a line (b). There will be primary end connection fluxes (e_1) going through the air

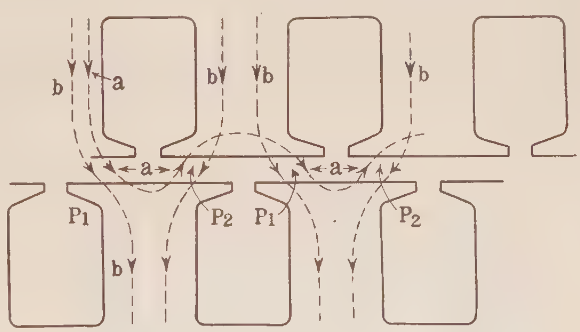


Fig. 2

around the coil ends. There will also be secondary end-connection leakages (e_2) going around the end rings of the squirrel-cage motor. These leakage fluxes actually exist separately of the main flux. In addition to these fluxes, there may be other end-connection fluxes (e_3), for instance, which go around the end rings of the secondary, but which go partly through the secondary core. As shown in this latter case, they may not exist separately, but again modify other fluxes.

It will be seen that the facts depend entirely upon the case, and that it is difficult to take into account the actual conditions

*A. I. E. E. Journal, Vol. XLI, 1922, April, p. 281.

for all the varieties which are met in practise. The main point is that we must always keep clearly before the student the conventions that are adopted in working out a problem.

P. Trombetta: If the self-inductive reactance of the primary

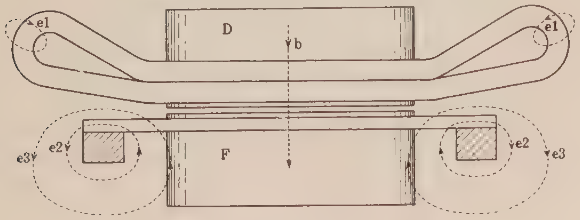


FIG. 3

of a transformer is X_0 and of the secondary is X_1 then if the voltage applied to the primary be E_0 the flux Φ_0 surrounding the primary must be such as to balance the voltage $E_0 - R_0 L_0$ where I_0 and R_0 are the current and resistance of the primary circuit.

When there is no load in the secondary the voltage induced in it is $E_0 - Z_0 I_0$ where Z_0 and I_0 are the impedance and current

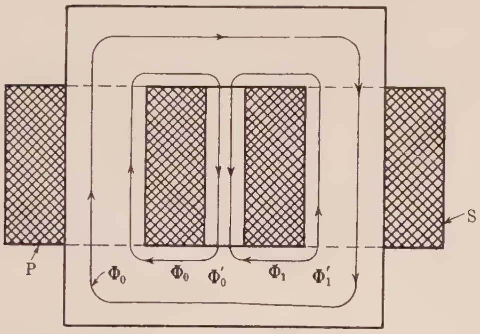


FIG 4

in the primary circuit. When there is a load in the secondary the voltage distribution in it is: $E_1 = E_e + Z_1 I_1$ where E_e is the voltage consumed in the load and $Z_1 I_1$ = voltage consumed in secondary impedance $Z_1 \; I_1 = \gamma_1 \, i_1 + j \, x_1 \, i_1 = i \, (\gamma_1 + j \, x_1)$

Now it is immaterial whether in the calculations of a transformer or an induction motor we assume that $j \, x_1 \, I_1$ is generated

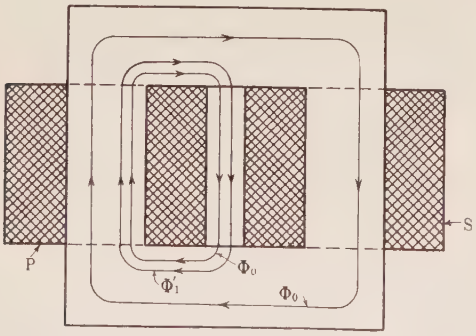


FIG 5

and consumed by the self-inductive reactance of the secondary circuit or that it is not generated at all. The most significant point to note is however, that this quantity can be found by finding the leakage reactance voltage of the secondary. The exact fact is, however, that this part of the secondary e. m. f. is not generated at all. In Fig. 4 is shown precisely what actually happens; namely, there are three different sets of lines of forces in the magnetic circuit of the transformer, Φ_0 may be called the main flux and goes through both the primary and secondary, Φ'_0 is the primary leakage flux and goes through the primary coil only, Φ_1' is the secondary leakage flux and goes through the secondary coil only. But it is seen that Φ_1' and Φ_0 are flowing in opposite directions inside of the core while Φ_0' and Φ_0 are flowing in the same direction inside of the core. In the primary, therefore, we have a real leakage flux which actually exists and represents a certain voltage consumption. In the secondary, on the other hand, we have conditions which cannot physically exist. On the outside of the secondary coil Φ_1' and Φ_0 can flow in the same direction and consequently what actually happens is that Φ_1' does not represent a real leakage flux but a part of the main flux which is taken from the inside of the secondary coil to the outside, that is, the flux inside of the secondary coil under load conditions is not Φ_0 but $\Phi_0 - \Phi_1'$ and since Φ_1' represents the leakage voltage, the actual voltage induced in the secondary is:

$$E_1 - j \, x_1 \, I_1 = E_c + \gamma_1 \, I_1$$

In other words, the total voltage induced in the secondary is the voltage consumed in the load plus the resistance drop in the secondary winding. The conditions above described are represented in Fig. 5.

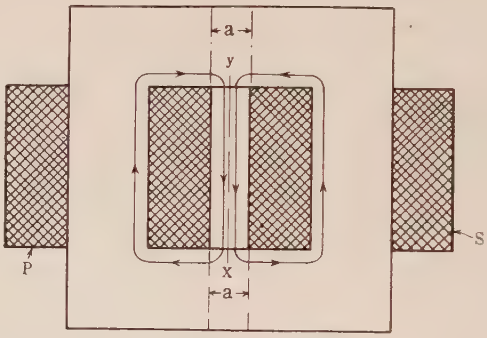


FIG 6

The basis for the above conclusions are to be found in the following physical explanation of reluctance and permeance.

It is well known that every substance (including vacuum which is not a substance but empty space) has a definite coefficient of permeability μ; in some cases this coefficient is variable, in iron for instance. For other substances it is constant. Taking into consideration the fact that we have definite knowledge of μ for those substances for which it is variable, we may state that having given the m. m. f. acting on a magnetic circuit of a certain substance we can calculate the flux flowing through that magnetic circuit. On the other hand if we apply a m.m. f. F_1 to a circuit in which there is already applied a m. m. f. $- F_1$ the resultant flux through that circuit is zero. This may be expressed mathematically in two ways first we may say that the total m. m. f. acting on the circuit is the summation of the two m. m. fs. F_1 and $- F_1$ and therefore equals to zero; second we may say that the permeability of the magnetic circuit has become zero. In either case we are correct. When F_1 is numerically larger or smaller than $- F_1$ there will be some resultant flux and if we write the equation

$$\phi = \frac{F_1}{R}$$

we find that R is very much increased if $F_1 > - F$; while if $F_1 < - F_1$, R actually becomes negative. On the other hand it is found that the permeability of the medium between the two coils has been greatly increased, in other words, in Fig. 6 the permeability of the iron included in the length "a" has become

of infinite reluctance while the air along the path $x\,y$ has been made more permeable.

That the application of a m. m. f. to a body is equivalent to increasing its permeability in one direction and decreasing it in the opposite is shown by the fact that electromagnets, whatever may be the nature of the core material, when placed in a magnetic field behave exactly in the same manner as a substance, the permeability of which is such that when exposed to the same field would increase the magnetic flux by the same amount that it would be increased by the new system with substance of different permeability and with a given m.m. f. applied to it.

In other words take (Fig. 7) a solenoid of diameter d and length l with copper core and let a current I flow through it. When this solenoid is placed in a uniform field of intensity H at an

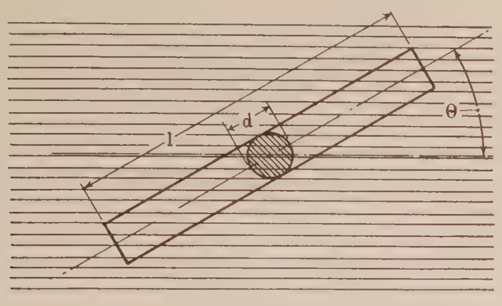


Fig. 7

angle θ to the axis of the solenoid, it will have a torque T tending to place the solenoid parallel with H. It is now possible to replace the solenoid by a cylinder of diameter d and length l which will give the same torque, provided the permeability is such that the increase in the amount of flux passing through the core for a given amount of rotation of the core is the same as in the case of the solenoid. In other words the torque or couple acting on the cylinder is

$$T = K \frac{d\,\phi}{d\,\theta}$$

Where ϕ is the flux passing inside of the cylinder and θ is the angle between the axis of the cylinder and the field intensity of the medium.

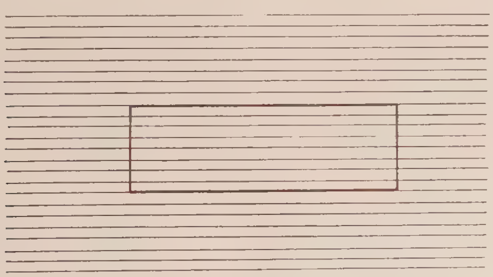


Fig. 8

A further proof of this theory is afforded by the converging or diverging lines into and away from a substance of permeability higher or smaller than that of the ambient in which it is placed, when the ambient has a magnetic field of uniform strength. Thus in Fig. 8 is shown a cylinder of a material of unity permeability placed in air parallel with a field of force of uniform density H, it is seen that the density inside of the rod is the same as that outside, in other words the rod has not converged the field at all.

In Fig. 9 is shown a cylinder of permeability $\mu > 1$ placed in a uniform field of density H. It is seen that inside of the rod the density is higher than it would have been if the rod were not there, while outside the cylinder the density is smaller than it would have been if the cylinder were not there. It is immaterial whether we consider the increase of the flux inside of the cylinder as being constituted by the flux which is now missing outside of it or if we consider all the additional flux inside the cylinder as returning outside of the cylinder in the opposite direction to that of the main field and therefore cancel or neutralize as many lines outside of the cylinder as there have been increased inside of it. In fact it is possible to study the field distribution inside and outside of a cylinder of permeability μ by replacing it by a solenoid through which is flowing a current which will give a field intensity of $H_1 - H$ where H_1 is the density in the permeable cylinder after it has been placed in the uniform field of density H. By exploring the field of this solenoid when placed in a medium of zero field density and unity permeability and superimposing this on the uniform field, we get the exact conditions as would exist when we place a cylinder of permeability μ in the uniform field H. It is evident that if μ of the permeable cylinder were $-\,\mu$ we could obtain all the field distribution in the same manner but the superposition would have to be so that the flux inside of the solenoid were flowing in opposite direction to the field H.

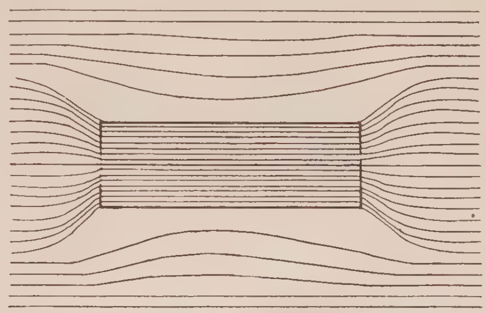


Fig. 9

What Mr. McEachron found by long, tedious and costly work might have been found analytically and much more accurately, and all of it is given in the first edition of Steinmetz's "Theory and Calculations of Electric Circuits," in the chapter on Reactance of Induction Apparatus, p. p. 217-231 (in particular at top of p. 229).

J. E. Clem: In my discussion of this paper I wish first to arrive at a mutual understanding of what the various fluxes are that are found in a transformer.

What is a leakage flux? The definition of the leakage flux should be a statement of the physical phenomenon. A leakage flux is ordinarily defined as a flux which links one winding without linking the other. Two leakage fluxes are sometimes recognized; the first being that produced by the primary current which links the primary but not the secondary and called the primary leakage flux; the second that produced by the secondary current which links the secondary but not the primary and called the secondary leakage flux. Actually, however, the idea of a secondary leakage flux is misleading and erroneous, there being only one leakage flux and that is the primary leakage flux. The leakage flux is the flux which links the primary winding but not the secondary winding.

There is no resultant flux inside a short-circuited coil except that required to supply the energy loss consumed in heat in the short-circuited coil. When the coil is on open circuit the current in the primary coil will cause a certain amount of flux to link the secondary coil, and if the coil is short-circuited a current will be set up and produce a counter flux. The counter flux set up by the current in the short-circuited secondary coil will be at all

times exactly equal and opposite to the flux coming from the primary current. Therefore the resultant flux inside the short-circuited secondary coil is zero.

The question immediately arises as to how the current can be maintained in a short-circuited coil with no flux inside it. We have seen that the condition of zero flux is in reality the balance of two fluxes. If the primary current should change there would be an excess of flux in one direction or the other which would induce a voltage and set up an additional current in the secondary coil. The current in the secondary coil will be maintained as long as no change of flux takes place inside the secondary coil.

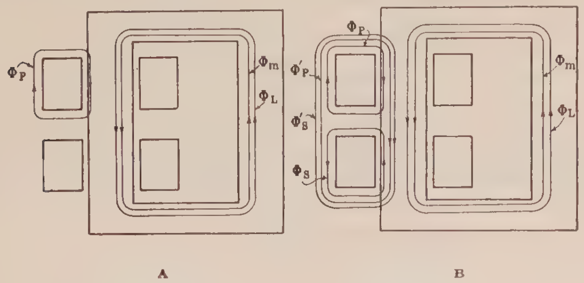


Fig. 10—Magnetic Flux Distribution in Transformers

Since there is no flux inside the secondary coil there can be no secondary leakage flux in the definition of the term as given above. Consequently all the leakage flux in a transformer must be primary leakage flux.

What is the main flux? This is primarily a matter of definition and the definition should be consistent and always lead to the same flux. There are three common definitions; (a) the flux in the core underneath the secondary windings; (b) the flux in the core at a point not underneath the primary or secondary windings; (c) the flux in the core required to maintain the secondary terminal voltage. The first definition is wrong because

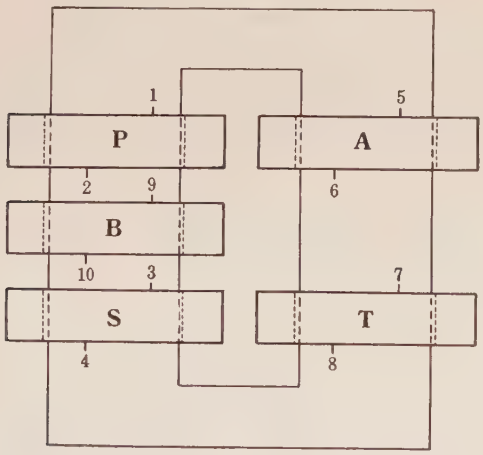


Fig. 11—Magnetic Flux Distribution in Transformers

the flux in the core under the secondary winding is different depending upon whether the primary is inside or outside the secondary. The second is wrong for a reason which will be given later in this discussion. The main flux then is the flux required to maintain the terminal voltage of the secondary winding.

The leakage and main fluxes as defined above are shown in diagram in Fig. 10A and 10B. In Fig. 10B ϕ_p and ϕ_p' are the fluxes which would exist if the coil *P* was by itself and ϕ_s and ϕ_s' are the fluxes corresponding for coil *S*. Of course in considering the coil alone the core must be assumed as taken away. In Fig. 10A is shown the resultant condition in which the leakage flux is ϕ_p linking the primary winding only. The flux ϕ_L is the flux required to supply the losses in the secondary coil and the flux ϕ_m is the flux required to maintain the terminal voltage of the secondary coil. It is clear that the leakage flux is the flux which links the primary but not the secondary and the main flux is the flux required to maintain the secondary terminal voltage.

The core flux at any part of the core will be the resultant of the various fluxes occurring there. Prof. McEachron's investigation was made to obtain experimental data in respect to the flux existing under the primary and secondary coils and elsewhere in the core. He considered that the text book method of representing the leakage fluxes as indicated in Fig. 1 of his paper required the leakage fluxes to have a separate and independent existence because they were represented by closed lines, and that they would be found along the edge of the core underneath the winding crowding the main flux to the middle of the core and further, that it should be possible to identify the separate fluxes because they were out of phase. Prof. McEachron's tests showed very conclusively that there was no resultant leakage flux within the secondary coil and that the flux within the primary coil was the resultant of the main flux and the leakage flux.

In Test *b*, impedance conditions, the secondary voltage corresponding to the flux inside the secondary coil is 6.14 volts. The voltage consumed in the resistance of the secondary coil is 6.16 volts. All the flux in the secondary coil is that required to supply the energy consumed in the resistance of the secondary coil and there is no other resultant flux inside the secondary coil.

Prof. McEachron's definition of the main flux as "the flux found in the core at a point not under either the primary or secondary windings" naturally led him into a wrong interpretation of the data obtained in test (*b*). According to his definition of the main flux the tertiary voltage should be a measure of the main flux, and he uses this voltage to determine what he calls the primary and secondary reactance. That the results of these calculations should be wrong is the result of the wrong assumption.

The tertiary voltage on the impedance test is a measure of the common reactance of the secondary and tertiary coil or it is a measure of the common induction of the primary and tertiary coils. If one wished to calculate the regulation one would use the difference between the primary applied voltage and the tertiary induced voltage, and if one wished to calculate the difference in voltage between the secondary and tertiary coils or the voltage induced in the tertiary coil one would use the tertiary induced voltage. The voltage induced in the tertiary coil depends upon the relative location of the tertiary coil in respect to the primary and secondary and therefore cannot be relied upon to measure the main flux density.

The variation of the voltage induced on the tertiary coil at different locations is clearly shown by the tests which I have made. The data are given in Table I, and were obtained from tests made on a transformer with the coils arranged as shown in Fig. 11. These tests were made by connecting the generator in turn to coils *P*, *S*, and *T*, with one or both of the other two coils short-circuited and measuring the voltage induced on all the other open-circuited windings. The voltage measured on the open-circuited coils varies with the relative positions of the generator, short-circuited, and open-circuited coils.

The voltage induced in any coil on the core during a straight impedance test can be predetermined if the values of the reactances between the various coils by pairs are known. The method of doing this is illustrated in Table II and the results of the calculation are tabulated in Table I. The voltage induced in a tertiary coil is equal to the secondary voltage plus the resistance drop of the secondary coil plus the common induced voltage of the primary and tertiary. The test and calculated

MAGNETIC FLUX DISTRIBUTION IN TRANSFORMERS

TABLE I

TABULATION OF TEST DATA AND CALCULATED VALUES

Test number	Generator			Induced				
	Volts	Amperes	Watts	Amperes	Amperes	Volts	Volts	Volts
1	1-2 392	60.5	213.0	3-4 59.8		5-6 211 *210.2	7-8 177 *181.4	9-10 196.7 *195.9
2	1-2 1027	60.5	18200		7-8 59.8	5-6 219 *208.7	3-4 835 *780	9-10 926 *880
3	1-2 365	60.5	2400	3-4 50.7	7-8 9.03	5-6 70.5 *97.4		9-10 182.4 *181.8
4	3-4 391.5	60.5	2160	1-2 59.8		5-6 174.5 *181.3	7-8 206 *210.1	9-10 196.7 *196.0
5	3-4 1016	60.5	17350		7-8 59.4	5-6 180.4 *181.9	1-2 845 *778	9-10 928 *873
6	3-4 361	60.5	2200	1-2 49.5	7-8 10.2	5-6 8.22 *68.0		9-10 181.0 *185.4
7	7-8 1036	60.5	18150	1-2 59.8		5-6 825 *783	3-4 197 *210	9-10 104.6 *109.6
8	7-8 1027	60.5	17300		3-4 63.0	5-6 855 *800	1-2 180 *186	9-10 95.5 *97.9
9	7-8 938	60.5	17250	1-2 28.6	3-4 31.1	5-6 746 *700		9-10 8.0 *24.4
10	1-2 403 *401.5 101	60.3 Load on (3-4) 60.0	2360 208			5-6 223 *220	7-8 187 *191	9-10 204.8 *206.6
11	1-2 990 *994 606	60.5 Load on (3-4) 60.0	11900 9290			5-6 809 *813.7	7-8 770 *785.6	9-10 791 *785.5
12	1-2 1035 *1047 10.0	60.5 Load on (7-8) 59.8	18200 204.0			5-6 228 *220.3	3-4 778 *783	9-10 942 *893
13	1-2 1610 *1615 595	60.0 Load on (7-8) 59.1	27400 9050			5-6 805 *876	3-4 1410 *1357	9-10 1503 *1458
14	391.7	60.2	2145			Average between 1-2 and 3-4		
15	1037	60.2	18200			Average between 1-2 and 7-8		
16	1006	60.2	17325			Average between 3-4 and 7-8		
17	1021	60.2	17350			Average between 7-8 and 9-10		
18	205.5	60.5	1675			Average between 1-2 and 9-10		

*NOTE—Calculated Values are Marked with *

TABLE 1—*Continued*

Lettering of Coils

1-2	3-4	5-6	7-8	9-10
P	*S*	*A*	*T*	*B*

Value of Reactance at 60 Cycles

P-S	*P-T*	*S-T*	*P-B*	*T-B*
T-A	*S-A*	*P-A*	*S-B*	*A-B*
6,486	16.46	15.98	3.385	16.26

Value of Resistance—Based on Wattmeter Readings

$R_P = R_S = R_T = 0.3$ when used as secondary

$R_P = T_T = 4.72$ when used as primary with other one as secondary

$R_S = R_T = 4.58$ when used as primary with other one as secondary

The difference in resistance whether used as secondary or primary is due to the difference in stray loss which must all be charged up against the primary winding.

MAGNETIC FLUX DISTRIBUTION IN TRANSFORMERS

TABLE II

Calculation of Voltages

Test No. 1

$P.F. = .0898 \quad W.F. = .9959 \quad I = 53.4 - j\,59.9$

$M_{PT.S} = \frac{1}{2}(6.486 + 15.98 - 16.46) = 3.003$

$M_{PA.S} = \frac{1}{2}(6.486 + 16.46 - 15.98) = 3.483$

$M_{PB.S} = \frac{1}{2}(6.486 + 3.385 - 3.385) = 3.243$

$E_T = (5.34 - j\,59.9)(.3 + j\,3.003) = 181.4$

$E_A = (5.34 - j\,59.9)(.3 + j\,3.483) = 210.2$

$E_B = (5.34 - j\,59.9)(.3 + j\,3.243) = 195.9$

Test No. 2

$P.F. = .2948 \quad W.F. = .956 \quad I = 17.73 - j\,57.45$

$M_{PS.T} = \frac{1}{2}(16.46 + 15.98 - 6.486) = 12.98$

$M_{PA.T} = \frac{1}{2}(16.46 + 6.486 - 15.98) = 3.483$

$M_{PB.T} = \frac{1}{2}(16.46 + 16.25 - 3.385) = 14.66$

$E_S = (17.73 - j\,57.45)(.3 + j\,12.98) = 780$

$E_A = (17.73 - j\,57.45)(.3 + j\,3.483) = 209.7$

$E_B = (17.75 - j\,57.45)(.3 + j\,14.66) = 880$

Test No. 3

$P.F. = .1093 \quad W.F. = .939 \quad I_S\,5.54 - j\,47.58 \quad I_T = .99 - j\,9.47$

$M_{SA.P} = \frac{1}{2}(6.486 + 15.98 - 16.46) = 3.003$

$M_{TA.P} = \frac{1}{2}(16.46 + 15.98 - 6.486) = 12.98$

$M_{SB.P} = \frac{1}{2}(6.486 + 3.385 - 3.385) = 3.243$

$M_{TB.P} = \frac{1}{2}(16.46 + 3.385 - 16.25) = 1.798$

$E_A = 365 - (5.54 - j\,47.58)(.3 + j\,3.003) - (.99 - j\,9.47)(4.72 + j\,12.98) = 97.4$

$E_B = 365 - (5.54 - j\,47.58)(.3 + j\,3.243) - (.99 - j\,9.47)(4.72 + j\,1.798) = 181.8$

Test No. 10

$P.F. = .344 \quad W.F. = .939 \quad I_S = 20.7 - j\,56.5$

$M_{PT.S} = 3.003$

$M_{PA.S} = 3.483$

$M_{PB.S} = 3.243$

$E_T = 10.05 + (20.7 - j\,56.5)(.3 + j\,3.003) = 191$

$E_A = 10.05 + (20.7 - j\,56.5)(.3 + j\,3.483) = 220$

$E_B = 10.05 + (20.7 - j\,56.5)(.3 + j\,3.243) = 206.6$

$E_P = 10.05 + (20.7 - j\,56.5)(.6 + j\,6.486) = 401.5$

Test No. 11

$P.F. = .2544 \quad W.F.\ .967 \quad I_S = 15.32 - j\,58.25$

$M_{PT.S} = 3.003 \quad M_{PA.S} = 3.483 \quad M_{PB.S} = 3.243$

$E_T = 606 + (15.32 - j\,58.25)(.3 + j\,3.003) = 785.6$

$E_A = 606 + (15.32 - j\,58.25)(.3 + j\,3.483) = 813.7$

$E_B = 606 + (15.32 - j\,58.25)(.3 + j\,3.243) = 785.5$

$E_P = 606 + (15.32 - j\,58.25)(.6 + j\,6.486) = 994$

values agree very well and bear out the statement that the tertiary coil is not a direct measure of the main flux.

Prof. McEachron could have found the quantities which he calls primary and secondary resistance and reactance much more easily by using an equation based on the analysis I have outlined. It should be remembered however that the quantities are not primary and secondary reactance. If we call the common induction of the primary and tertiary when the secondary is short-circuited M_{pt} then the tertiary voltage will be

$$E_t = I\,(R_s + j\,M_{pt})$$

But $E_t = 24$; $I = 4$; and $R_s = 1.54$, from which M_{pt} is easily found to be 5.8 ohms. Now M_{pt} plus M_{st} must equal X_{rs} and we get M_{st} as 8.85 ohms. The calculations in the paper for the voltage E_m are correctly made although they give the total voltage induced in the tertiary coil and not the voltage induced by the main flux only.

Following is a brief summary of the main points in respect to the magnetic flux distribution in transformers.

There is but one leakage flux and that is the flux which links the primary but not the secondary.

There is no resultant flux inside a short-circuited coil except that required to supply the energy loss in the short-circuited coil.

The main flux is the flux required to maintain the terminal voltage of the secondary winding.

At any point in the core the various fluxes in the core do not have a distinctly separate and independent existence, but the flux at any point is the resultant of the different fluxes at that point.

The voltage induced in the secondary coil is equal to the secondary terminal voltage increased by the resistance drop in the secondary coil.

The voltage induced in the primary coil is equal to the secondary induced voltage increased by the voltage induced by the primary leakage flux.

The voltage induced in any other coil on the core depends upon its relative position in respect to the primary and secondary coils.

The practise of illustrating the various fluxes by closed lines is in general correct because the leakage and main fluxes can exist independently of each other. Whenever two or more fluxes occur at the same point the effective flux is their resultant.

Philip L. Alger: This question of the distinctions between "main flux" and "leakage" is an ever recurring one in the study of electrical machinery. Especially in the consideration of the zigzag leakage or "doubly linked" flux of induction motors are the distinctions difficult to keep in mind. In all cases one has the alternatives of either considering but one flux from which driblets keep leaking away as its path is traced further and further away fron the primary source of m. m. f.; or of considering a "main" flux constant throughout the circuit, and various leakage fluxes which flow sometimes with and sometimes against the "main" flux. As an enemy is always defeated more easily in detail than en masse, the latter point of view has advantages for quantitative work, and I prefer it.

While the two points of view, if carried out correctly, will always lead to the same result, the single flux theory is the more fundamental, and should always be resorted to in doubtful cases. Mr. McEachron has presented an interesting experimental proof of this fundamental nature of the single flux viewpoint.

I believe, however, that by modifying his arrangements, Mr. McEachron could have experimentally proved the separate existence of the primary leakage flux (though not that of the secondary). For, if the primary leakage flux actually did try to hug the outer edges of the core as shown by Fig. 1 of the author's paper, the difference in phase between it and the main flux would cause a corresponding difference in the reluctance drops in the iron, and this difference between the m. m. f's. in two adjacent parts of the core would divert the leakage flux in a transverse direction until the m. m. f's were equalized. In other words it is the low reluctance of the core in a direction at right angles to the flow of the main flux (in the section of Fig. 1) that forces the primary leakage and main fluxes to mingle indistinguishably. The question is analogous to that of the distribution of high-frequency current in a slot embedded conductor.

If, therefore, the holes for the research coils had been pierced at right angles to their chosen positions, in the same plane, so that the wires passed *between* instead of *through* the laminations, and if the outer search coils had been so placed as to include only a few of the outermost laminations, a different result would have been found from the experiments. For, in this case the relatively high transverse reluctance of the core, due to the spaces between laminations would have permitted the primary leakage flux to retain its identity more distinctly.

The 15 to 20 per cent excess of density at the middle of the core disclosed by the tests is very interesting. Such differences account for part of the inevitable excess of test core losses over those calculated from the laboratory data. I believe that this variation in density over the core section is due to the fact that the flux always takes a path which combines minimum length with minimum curvature in so far as these qualities are compatible. If the proportions of the test transformers had been different, so that the corners had played a greater (or less) part in determining the flux distribution, I believe the variation of core density would have been correspondingly altered.

P. Trombetta: I still cannot see why it is necessary to make so many assumptions. It seems to me that if the relations are studied properly it is possible to determine all leakage fluxes and when they are known it soon becomes apparent what can and what cannot be neglected. It is perfectly possible to calculate or measure leakage fluxes of primary and secondary at different values of currents and when the two are coexisting in the same magnetic circuit it is only a question of combining all of them and the resultant gives the actual facts.

Benj. F. Bailey: I think the fundamental trouble here perhaps is this. Most of the text books use in a great deal of their work the principle of superposition, yet they never take the trouble to explain that they are using that principle, or what it means. There are a great many effects that can be superimposed upon one another and treated individually. In other words they don't interfere with one another. I look, for example, at the blackboard and I see perfectly what is written there, yet there are innumerable light waves coming across the light waves which reach my eye, but there is not a particle of interference. That is superposition. It is hard to define what we mean by it, but that is simply an illustration of it. There are plenty of places where we can use superposition to advantage. But there are other places where we cannot. One of these is when we come to superimpose magnetic fields. They do not superimpose perfectly because of the change in permeability. Most of the electrical books explain magnetic phenomena on the principle of superposition, but do not make it clear to the student that that is the principle upon which they are working, and also do not make it clear that it may lead to slightly erroneous results. For example in the case of the transformer, they are not taking into account the fact that magnetic effects are not perfectly superimposable. There are changes in permeability, and consequently the result you get is not quite right.

I quite agree with what has been said about the sloppiness of some of our text books. I am a teacher myself, and I have to contend with it every day. It is certainly disconcerting to have to explain to students why the textbook is not right,—and it is not right in a very great many cases.

I think sometimes we might get rid of a good many of the troubles of teaching if we came to the idea of teaching the student that there is no difference at all between a-c. and d-c. current. In other words, Ohm's Law always holds, or the current is the electromotive force divided by the resistance. For example, consider a simple reactive coil. There is an applied voltage on the coil and another voltage induced in the coil. If we take into account both of them and call the sum the electromotive force, then Ohm's law is followed exactly. Now I don't say that I want to teach that way. I am sometimes discouraged, because when I do try to get down to fundamentals and make the thing clear from the ground up, I find it is very difficult to do.

K. B. McEachron: As stated by Mr. Trombetta, a theoretical treatment of the subject of leakage in a transformer may be found in "The Theory and Calculation of Electric Circuits" by Dr. Steinmetz. The present paper attempts only to show in an experimental way the fluxes which are actually found, and to point out how the assumptions frequently made concerning the

leakage fluxes may lead the student into an altogether wrong conception of the true conditions.

Mr. Clem in his discussion stated that the method used in determining the main flux does not give a correct measure of this flux. Strictly speaking, that is true, but for this test, it was desirable to obtain a separation of the so-called primary and secondary leakage fluxes. Tests have been made since this paper was written in which I have found, as Mr. Clem stated, several values depending on the location of the tertiary coil. The choice of location of the tertiary coil would not change the final result as outlined in the paper unless placed very close to either the primary or secondary windings.

The possibility of finding the leakage flux in the outer laminations as suggested by Mr. Alger introduces some interesting possibilities. Using the same test core, four belt coils of 40 turns each were wound around equal sections of the core under the middle of coils 7 and 8 shown in Fig. 3 of the paper. To provide sufficient space between laminations for the 80 wires of two adjacent coils it was necessary to separate the laminations 0.03 in. (0.79 mm.). This separation was made only at the point where the coils passed through the core. This arrangement, of course, introduced considerable reluctance in a transverse direction which a core tightly clamped would not have, but does, to some degree, represent the condition in a core where ventilating ducts are used.

The belt coils were numbered 9, 10, 11 and 12, 9 and 12 being on the outside. The procedure followed in making the tests was the same as that described in the paper. Coils 20 and 21 were used as the primary, all tests being made with transformer coils 7 and 8 as the secondary. The first test at no load showed a flux density of 4640 lines in the outer section under belt coil 9, and 4810 in the inner section under coil 10. The oscillograms which were taken all show the same displacement of the belt coil currents with respect to the impressed voltage. This result means that the flux at no load is evenly distributed across the core under the secondary.

With coils 7 and 8 short-circuited and 4 amperes flowing through the windings, a very different result is found. The results are given in the table, the nomenclature being the same as that used in the paper.

Impedance Conditions

Calculated			Belt Coil Tests		
Voltage	B_{max}	Degrees displacement	Belt coil no.	B_{max}	Corrected* angle
E'_p	2790	3.7 lead	9	900	151 lag
E_m	1190	7.5 lag	10	480	6 lag
$I_s X_s$	1100	169.3 lag	11	560	8 lag
E'_s	280	79.2 lag	12	790	152 lag

*The corrected angles are measured on the oscillograms and diminished by the angle found under no load conditions.

Combining the belt coil fluxes, with their respective angles taken into account, gives an average density over the entire core of 260 lines per sq. cm. with a lag angle of 115 deg. In magnitude this corresponds closely to the value of flux required to induce sufficient voltage to overcome the $I R$ drop in the secondary. The phase position does not check very closely.

Considering the position of the belt coil fluxes, it is plain that considerable leakage flux is to be found in the outer laminations, but after all in this particular case such flux is less than 1/3 of the total secondary so-called leakage flux. In the two middle belt coils a flux is found which corresponds to the so-called mutual or main flux in phase position but of less than 1/2 the calculated density. Since the main flux density is calculated on the entire area of the core, something less than 1/4 of the main flux is found.

That some flux due to the secondary and primary turns should be found in the outer laminations is only to be expected when the reluctance of the path perpendicular to the plane of the laminations is taken into account together with the high m.m.f. acting when the transformer is operating under load. In the case of a core with ventilating ducts high flux densities may be found under loaded coils which will tend to change the losses from those calculated assuming a uniform density across the entire core.

Correspondence

To the Editor:

In his very interesting letter (August JOURNAL) on the subject of remuneration of engineers, Mr. Katzman attributes the fact that the engineering profession is paid very poorly to the attitude of injurious modesty on the part of the engineer whenever the question of salary is raised. One need not look, far from Mr. Katzman's letter to find evidence of his contention that this spirit of modesty is encouraged by the spokesmen of the engineering societies. On the very same page, in a paper on training of engineers, Mr. Milton argues that colleges should teach modesty as most modest men are thinkers.

It is unquestionably true that men of great technical ability are as a rule modest, and many years of observation have led the writer to believe that Mr. Katzman is right in asserting that under present conditions this modesty has a tremendously detrimental effect on the development of the engineer. The point that study after leaving college is more essential to the development of better engineers than extending or intensifying of college courses, and that consequently salaries should be adequate to secure the necessary leisure time and freedom from worry, appears to the writer to be particularly well taken. Besides being too modest, many engineers of marked ability are perhaps also too trusting for their own good. In solving the problem confronting him, the engineer has it forcibly impressed on his mind that if natural laws are violated the penalty is swift and sure. The consequences of mistakes in his calculations can not be evaded by skillful arguments or eloquent appeals. Only strict adherence to natural laws insures success.

There is strong evidence for believing that a law of compenstion justly equalizes penalties and rewards when applied to social groups or nations over sufficiently long periods of time, but from his constant contact with natural forces the engineer too often draws the inference that this law of compensation operates just as strictly in individual relationships. If, therefore, his remuneration is small he is apt to conclude that it, approximately at least, is a measure of the services rendered, and no wonder there is hesitancy on his part about discussing what may be looked upon as a sign of inferiority. If commerce and industry were based on a fair exchange of service for service, as the engineer generally assumes it is, such traits as modesty and faith in one's fellowmen would be very desirable and to be highly commended.

Professor C. A. Adams, in his presidential address to the Institute (TRANSACTIONS XXXVIII, Part 1, Page 792) clearly sets forth that such equitable distribution of wealth is impossible when monopolies exact their tribute from industry, and he also points out that land monopoly is the most unfair, the most dangerous and the most far reaching in its influence. To quote from his address:

> The site (or unimproved) value of land in this country constitutes about one half of our national wealth, yet the landowning class as a group, taken from the beginning of the settlement of the country, have been made a free gift of that wealth, which is the product of the industry of society as a whole. This is a statement which can not be controverted.

If some have received wealth without earning it, equal in value to about one half of our national wealth, the necessary corollary is that others must have earned an equal amount without receiving it. In view of this, any claim that one's income is even approximately a measure of one's usefulness to society, is obviously preposterous. The writer recommends the careful and earnest consideration of the remedy briefly discussed by Professor Adams.

K. L. HANSEN

The Stroboscopic Method of Speed Measurement

BY VAL. A. FYNN
Fellow, A. I. E. E.
Consulting Engineer, St. Louis, Mo.

EVERY engineer knows how difficult it is to make accurate speed measurements and how essential accuracy is in certain cases, for instance, in testing and experimental work.

In practise, speed counters and tachometers are generally used. The first register the number of revolutions made by the machine in a given time and must be employed in connection with a time measuring device, usually a stop watch. Here the sources of error are slip and the notorious inaccuracies of stop watches. The speed counter should be applied from 30 to 60 seconds, but during that time many changes can take place in the operation of the machine under test. Slip errors can be held down by the exercise of constant care or entirely eliminated by using suitable drives, but such drives cannot always conveniently be employed.

Tachometers register the rate of speed, give instantaneous records, are independent of time-measuring devices but require more or less frequent calibration and are also subject to slip errors. Tachometers of the magneto type are the most satisfactory. If regularly calibrated, used in connection with high-class voltmeters and driven by means of gears or rubber belts cooperating with sufficiently large pulleys, reasonably accurate results are secured. But it is not always feasible to drive a tachometer by means of pulleys or gears and even the best of the tachometers with perfect drives are not sufficiently accurate for all classes of work.

Tachometers of all types require an appreciable amount of power to drive them, and cannot be used for accurately measuring the speed of fractional horse power motors because they put an unknown and varying load on the motor which is a substantial percentage of the rated output of the machine and therefore materially affects the speed thereof. Speed counters are equally unsatisfactory for very small motors because they too require some power to drive them and when pressed sufficiently hard against the shaft to avoid slip, put an appreciable friction load on the motor.

One of the most difficult problems is to measure the speed of an asynchronous motor. Such measurements are primarily made with a view to ascertaining the "slip" and the difficulty arises from the fact that this slip does not amount to more than a few per cent of the synchronous speed. The speed counter is perfectly hopeless for this kind of work and the best tachometers are insufficiently accurate even when perfectly driven. In addition to this, it is seldom possible to provide any tachometer drive at all.

All these difficulties have been long understood and many attempts have been made to overcome them in a practical manner. The ideal speed measuring device must be simple enough for everyday use, must respond instantaneously to speed changes, be sufficiently accurate for all practical purposes and must not put any load on the machine under test. As far as the writer knows, stroboscopy offers the only possibility of satisfying the conditions named. Much successful work has been done along this line, for instance, by Lorenz, Benischke and particularly, Dr. Drysdale. The writer has merely followed in the footsteps of these investigators in designing and building the apparatus which, for sometime past, has been in successful use in the research and experimental department of the Wagner Electric Mfg. Co. The details of its design have been influenced by the desire to utilize as much of the apparatus already on hand as could be made use of for the purpose in view.

The outfit consists of a stroboscopic primary standard used for calibrating purposes, of a stroboscopic slip-meter for asynchronous motors, permitting of instantaneous readings, of a stroboscopic device for instantly ascertaining the speed of any kind of motor and of a number of tachometers of the magneto type. Other types of tachometers, also speed counters, are in use but are not relied upon for accurate work.

The magneto type of tachometer in conjunction with a positive drive and an accurate voltmeter, scaled to read direct in rev. per min. is used whenever possible with due regard to the limitations of this type of speed measuring device. All tachometers are frequently calibrated.

The calibrating device is based on the tuning fork. The rate of vibration of such a fork is of extraordinary accuracy, well beyond the requirements of any ordinary laboratory. According to Prof. D. C. Miller, a good tuning fork is subject to about the following variations: An increase of temperature of one deg. cent. diminishes the frequency of the fork by 0.011 per cent; an increase in the amplitude of a fork, caused to vibrate by striking it with a felt hammer, decreases the frequency by not more than 0.002 per cent for such changes of amplitude as occur in practise; an increase of the amplitude of an electromagnetically driven fork from 0.75 to 2 millimeters reduces the frequency 0.01 per cent; electromagnetic driving of a fork increases its frequency; in one case this increase was found to be 0.025 per cent.

Any periodic phenomenon, however rapid, can be seemingly arrested at any desired point by means of a stroboscope, thus if a radial line or spoke be drawn on a disk and the latter revolved at a certain speed, the line can be caused to appear stationary by observing the disk at certain intervals of time only, or illumi-

nating it by light flashes of a certain frequency and observing same from any convenient angle. Uninterrupted observation or continuous illumination of the disk will merely show a somewhat blurred surface. Interrupted observation of the disk with the spoke can be secured by revolving another disk provided with a radial slot past a stationary shield having a corresponding slot and keeping the eye in line with the first disk and the stationary slot. The disk with the spoke will be seen every time the two slots coincide. Interrupted illumination of the disk with the spoke can be secured by substituting a source of light for the eye. The frequency of observation or illumination can be varied by varying the speed of revolutions of the moving slot or by varying the number of such slots.

If the disk with the spoke is rotated at a constant speed of, say 1000 rev. per min., the spoke will pass any fixed point 1000 times per minute and will appear stationary in space if illuminated at the rate of 1000 flashes per minute. If the flashes occur when the revolving spoke passes the 12 o'clock position, it will appear to be stationary at that point. Flashes constantly occurring one quarter of a revolution later will show the spoke at 9 or 3 o'clock, according to the direction of rotation of the disk carrying the spoke.

But other ratios of disk revolutions to number of flashes produce stroboscopic effects. As long as the disk makes one or more complete revolutions between two successive flashes, in other words, when the ratio of revolutions to flashes is n:1, where n is a whole number, the stationary image remains a single radial line. When the number of flashes is a multiple of the number of revolutions of the disk, the stroboscopic image is stationary, but can be a multiple of the original. Thus if a single spoke revolving at 1000 rev. per min. is viewed by the intermittent light of 3000 flashes per minute, three stationary spokes displaced by 120 degrees will be seen. While each of the three spokes is illuminated at the rate of 1000 flashes per minute, as in the case of the number of revolutions and flashes being equal, yet because the illumination produced by each flash diminishes as the number of flashes per minute increases the stroboscopic images which are a multiple of the original are less bright than those which are identical with the original.

What is true of the spoke is also true of all kinds of geometrical figures. Thus a square viewed in the light of a fixed number of flashes per minute will appear stationary and single at one set of speeds, stationary and double at another, stationary and triple at a third, and so on. A triangle, a pentagon, a hexagon, each has a set of distinctive speeds at which it appears as single, double or triple figure. Such geometrical figures are easily recognized and distinguished and since each corresponds to definite and different ratios between speed of figure and number of flashes a combination of such figures on a single disk can be made to cover a very wide range of speeds.

Since it is extremely easy to tell when a figure is stationary, stroboscopic speed measurements can be made with the same accuracy with which the tuning fork vibrates. It has been shown that this accuracy is well within .02%. But it is interesting to know the magnitude of the error which is introduced in case the reading is taken when the stroboscopic image is not stationary. If a figure-carrying disk, observed with the help of a tuning fork, departs from that speed which produces a stationary image, the latter begins to rotate, revolving in a direction opposed to that in which the disk revolves in case the speed of the latter drops, and vice versa. The more the disk "slips" the faster the figure will rotate. The number of revolutions per minute of the figure is equal to the "slip" of the disk and is a direct measure of the error introduced by taking a snap reading at a time when the stroboscopic image is moving.

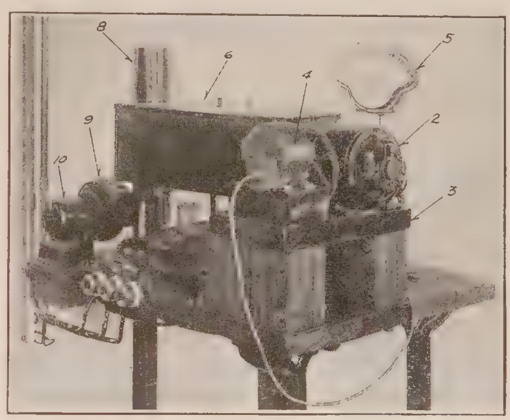


Fig. 1—Complete Calibrating Device

The complete calibrating device is shown in Fig. 1, while Figs. 2 and 3 are views of part of this apparatus. An adjustable-speed d-c. motor 2 is located on a base 3 and carries on its shaft a disk 11 upon which are displayed four concentric geometrical figures. The motors haft is geared 1 to 2 to a transverse shaft 12 which carries a pinion at one end and is cupped at the other. This shaft drives the speed measuring device which is to be calibrated. Magnetos such as 4 are driven by the pinion, tachometers with point drive are pressed against the cupped end. The voltmeter 5 in Fig. 1 is the indicator cooperating with the magneto under test. An electromagnetically driven, 50-cycle tuning fork 7 carrying a shutter near the extremity of its prongs, as well seen in Fig. 3, cooperates with a 300-watt incandescent lamp located in the brass pipe 8 and so positioned as to illuminate the geometrical figures through the slits in the shutter. In order to protect the tuning fork from the heat developed by the incandescent lamp, a blower 9 driven by the motor 10 is arranged to circulate air through the pipe and a thick sheet of micanite 13 is interposed between the pipe and the fork. In order to make it possible to

work this apparatus in the day time, a sheet iron box 6 with a removable cover and with an observation window encloses the disk carrying the geometrical figures and reaches close up to the shutter on the fork. The observation window is located at the tuning fork end. The fork is set in motion by means of the wooden pliers-like device seen in Fig. 1 just below the blower. The dry cell seen in the figures keeps the fork vibrating, the resistances shown are included in the shunt circuit of the motor and serve to adjust its speed. The finer adjustments are obtained by means of slide wire resistances mounted on the side of the box 6 not shown in Fig. 1 and are within easy reach of the operator sitting at the observation window. The various electrical circuits are controlled by means of the switches seen in Fig. 1.

The motor is a 110-volt shunt machine of ⅓ h. p. at 1500 rev. per min. Its speed is varied from 100 to 4000 rev. per min. by means of voltage, armature and field circuit resistance control and no difficulty is experienced in securing stationary stroboscopic images at any of the speeds as long as the voltage of the source of supply is constant.

In order to secure clear cut images it is necessary that the disk carrying the geometrical figures run true, that the figures be concentric and that the light flashes be separated by periods of total darkness. The fork is calibrated for an amplitude of 2½ mm. and each wing of the shutter carries two slits 10 mm. long, 0.25 mm. wide and 7.5 mm. apart. When the fork is at rest the slits in the two wings coincide. Under these conditions the light flashes are perfectly defined. The

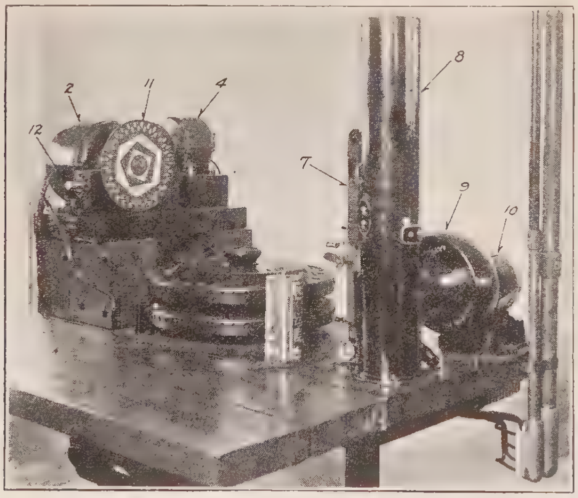


Fig. 2—Part of Calibrating Device

amplitude of the fork can be adjusted by changing the setting of the fork-operated interrupter connected in the circuit of the electromagnet which is located between the prongs of the fork. Two slits are used in order to get a more uniform illumination of the disk 11. With a more concentrated source of light, or for viewing the disk directly through the shutter, a single and wider slot will do as well or better. One wing of the shutter can, of course, be stationary and the other attached to one prong of the fork, the latter must be calibrated at a known temperature and with the shutter in place. A 50-cycle fork produces 6000 flashes per minute.

The outer geometrical figure consists of two radially displaced rows of 30 short, equally spaced, radial lines,

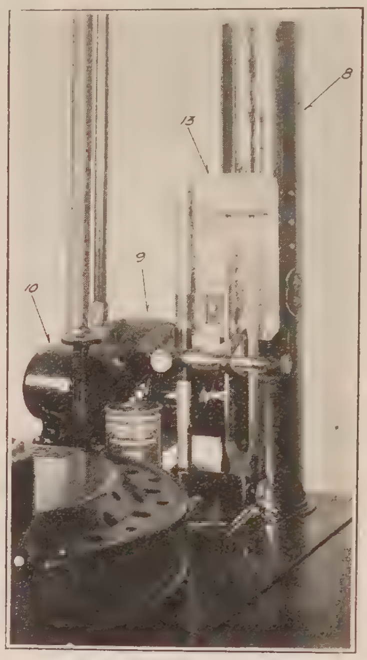


Fig. 3—Part of Calibrating Device

the 30 on one row being circumferentially displaced by six degrees from the 30 in the other row. The number of lines of each row passing a given point, each minute is thirty times the rev. per min. of the disk, or 6000 at 200 rev. per min. This figure will therefore appear stationary and single at 200 rev. per min. and all multiples thereof. At 100 rev. per min., each row will appear double and stationary with the result that a stroboscopic figure composed of 60 radial lines of double their true length will be seen. This will occur at 100, 300, 500 rev. per min. and so on. The sexagon will appear stationary and single at 1000 and double at 500; the pentagon stationary and single at 1200, double at 600, triple at 400, and the square stationary and single at 1500, double at 750 and triple at 500. Single, double and triple stationary images will also be had at other speeds as shown in Table I. The speeds at which single stationary stroboscopic images appear are found by dividing the flashes per minute by the number of elements in the original figure and multiplying by any whole number as by 1, 2, 3, 4..... and so on. Double stationary stroboscopic figures appear at speeds found by multiplying the same quotient by any odd number of halves as by 1/2, 3/2, 5/2.........and so on. Triple stationary stroboscopic figures appear at speeds found by multiplying

said quotient by any number of thirds not divisable by three, as by 1/3, 2/3, 4/3........and so on.

Table I makes it plain that calibrating curves with enough points for almost any purpose can readily be obtained with the device of Fig. 1. This table is, of course, easily extended to 8000 rev. per min. which is the upper calibration limit of the apparatus. Temperature corrections should be made whenever the fork temperature during the test differs from that at which the fork was calibrated.

TABLE I

Disk speeds at which stationary stroboscopic images of various disk figures appear when viewed with a 50-cycle tuning fork. *S* stands for single, *D* for double and *T* for triple image.

Disk speeds	Disk Figures			
	4 point	5 point	6 point	30 point
100	..	..	..	*D*
200	..	..	..	*S*
300	..	..	..	*D*
400	..	*T*	..	*S*
500	*T*	..	*D*	*D*
600	..	*D*	..	*S*
700	..	..	..	*D*
750	*D*	..	..	..
800	..	*T*	..	*S*
900	..	..	..	*D*
1000	*T*	..	*S*	*S*
1100	..	..	..	*D*
1200	..	*S*	..	*S*
1300	..	..	..	*D*
1400	..	..	..	*S*
1500	*S*	..	*D*	*D*
1600	..	*T*	..	*S*
1700	..	..	..	*D*
1800	..	*D*	..	*S*
1900	..	..	..	*D*
2000	*T*	*T*	*S*	*S*
2100	..	..	..	*D*
2200	..	..	..	*S*
2250	*D*	..	..	..
2300	..	..	..	*D*
2400	..	*S*	..	*S*
2500	*T*	..	*D*	*D*
2600	..	..	..	*S*
2700	..	..	..	*D*
2800	..	*T*	..	*S*
2900	..	..	..	*D*
3000	*S*	*D*	*S*	*S*
3100	..	..	..	*D*
3200	..	*T*	..	*S*
3300	..	..	..	*D*
3400	..	..	..	*S*
3500	*T*	..	*D*	*D*
3600	..	*S*	..	*S*
3700	..	..	..	*D*
3750	*D*	..	..	..
3800	..	..	..	*S*
3900	..	..	..	*D*
4000	*T*	*T*	*S*	*S*
4100	..	..	..	*D*
4200	..	*D*	..	*S*
4300	..	..	..	*D*
4400	..	*T*	..	*S*
4500	*S*	..	*D*	*D*

The stroboscopic slipmeter is illustrated in Figs. 4 and 5; it comprises a synchronous self-starting motor 15 controlled by the switch 25 and mounted on a base 14 provided with handles. This base supports a cone 16 driven by the motor through mitre gears, a stationary rod 17 and a revoluble threaded rod 20 controlled by the milled head 21. Slidably mounted on the rod 17 is a carriage 26 which supports a disk 18 mounted on ball bearings and provided with a segmental opening, also a fixed shield 19 provided with a corresponding opening and an indicator disk 22. The disk 18 is adapted to be driven frictionally by the cone. A nut cooperating with the screw 20 engages the carriage 26 and moves it longitudinally when the screw is turned by turning the milled head 21. The travel of this nut is limited in both directions by suitably placed stops

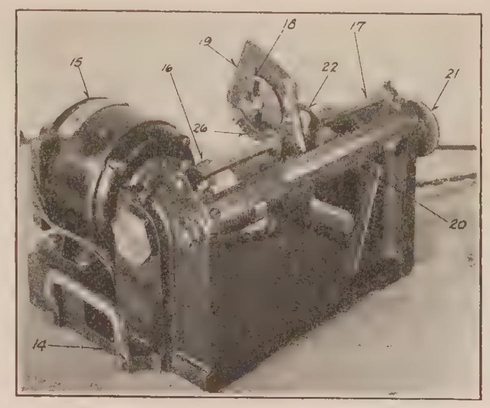


Fig. 4—View of the Stroboscopic Slipmeter

best seen in Fig. 5 which also shows the catch provided for holding the disk 18 out of contact with the cone. The position of the disk relatively to the cone is shown on the scale 24 by the indicator 22, the zero of the scale corresponding to that disk position in which its speed equals that of the cone. This is the case when the disk contacts with a cone circumference equal to its own. The cone, disk and traversing gear are protected

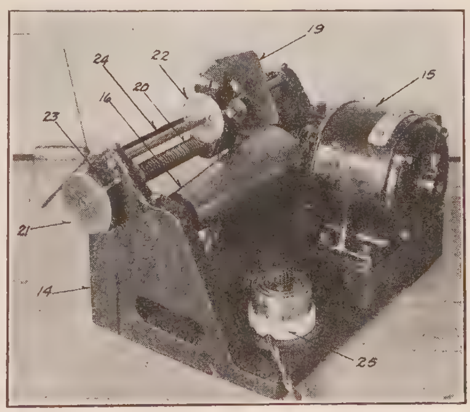


Fig. 5—View of the Stroboscopic Slipmeter

from mechanical injury by a cover not shown in the photographs.

In using this apparatus for measuring the slip of asynchronous motors, a suitable figure is painted on a shaft end of the motor under test, the synchronous motor 15 is connected in parallel with the asynchronous machine, the disk 18 is driven by the synchronously revolving cone and the figure on the shaft end is observed through the slot in the shield 19. To measure

a slip the milled head 21 is turned in the one or the other direction until the figure on the shaft appears stationary, when the scale is read. The scale is not only arranged to read direct in per cent slip, but the diameter of the disk 18 and the angle of the cone are so chosen that one revolution of the milled head 21 corresponds to 1 scale division or to one per cent slip. The 2¼ in. milled head is divided into 20 parts, thus making it possible to read to 1/20th and estimate to 1/100 of a per cent. As it would be practically impossible to make the screw, the nut and the fork of the nut engaging the carriage 26 without endplay, it is necessary to allow for such endplay as exists by handling the milled head 21 like the dividing head on any tool. The final position must be reached by revolving the milled head in one and the same direction. It is immaterial in which direction the head is turned, just so this direction is not reversed just before a reading is taken. Since the zero point for the milled head alters with the direction in which it is rotated, the stirrup 23 carries two reference arrows, one for a clockwise, the other for a counterclockwise, direction of rotation of 21. The fractions of a per cent are read from the one or the other reference arrow according to the direction of rotation used. There is no endplay between disc and linear scale and no such correction is there necessary. The longitudinal movement X of the indicator 22 is given by either of the following expressions:

$$x = \frac{d \times l}{d_2 - d_1} \frac{s}{100} = \frac{r}{\tan \alpha} \frac{s}{100}$$

where d is the diameter of the disk 18, l the length, d_2 the maximum, and d_1 the minimum, diameter of the cone, s the slip in per cent, r the radius of the disk 18 and α the angle which the generating line of the cone forms with the axis thereof. The scale 24 has equal divisions.

It is convenient to dimension the apparatus so that speeds of about 30 per cent below and about 15 per cent above synchronism can be measured with the same disk and cone, thus making the apparatus available for testing asynchronous generators and compensated motors. The same slipmeter will measure the slip of a motor with any number of poles provided the figure rotated by the motor under test has the proper number of elements. Various frequencies are taken care of by designing the synchronous motor to operate sufficiently well over the desired range of periodicities. The rotating figure can be observed directly through the slot in the stationary shield 19 or viewed by flashes of light projected through this slot.

It is, of course, desirable to keep the wear on the cone and disk down to a minimum. To this end, the disk should not be run longer than necessary and there should, of course, be no slip at all between the two. It has been found that good traction with a very small pressure is secured by using a ground brass cone and an aluminum disk. The pressure of the disk on the cone is regulated by suitably counterbalancing the carriage 26.

In the illustrations, the cone runs at the same speed as the four-pole motor which drives it. Since the disk has one slot, 1800 flashes will be produced at synchronism when operating on a 60-cycle circuit. It is clear that in case of a 60-cycle four-pole motor, its slip can be ascertained with a figure having a single element, for instance, a single segmental spoke. This spoke will pass a fixed point of 1800 times a minute and will, therefore, appear stationary when viewed by 1800 flashes per minute. When the motor, and therefore the spoke, slips, the disk 18 must be caused to alter its speed correspondingly by turning the milled head 21, thus again arresting the stroboscopic image. A six-pole, 60-cycle motor should carry three equally spaced segmental spokes, a triangle or the like. Tables II and III show the number of equally spaced elements required by figures revolved by 60-cycle test motors of different number of poles in order that stationary stroboscopic images may be secured by a cone running at 1800 and 1200 rev. per min. respectively, and co-operating with a single-slot disk.

It will be found of advantage not to run the cone and disk too fast. A suitable speed can be readily selected by changing the gear ratio between motor and cone. A cone speed of 900 will be found satisfactory as to operation and wear; it requires the same set of shaft figures as an 1800 cone speed. The disk may have more than one slot. Any of the figures can be painted on a shaft end of the test motor or on a small disk firmly secured to the shaft. No great accuracy of outline or concentricity is required.

TABLE II
Shaft figures for use with 1800 flashes per minute

Poles of test motor	Synchronous rev. per min.	Number of elements
2	3600	1
4	1800	1
6	1200	3
8	900	1 or 2
10	720	5
12	600	3
14	514.3	7
16	450	2 or 4
18	400	9 and so on

TABLE III
Shaft figures for use with 1200 flashes per minute

Poles of test motor	Synchronous rev. per min.	Number of elements
2	3600	1
4	1800	2
6	1200	1
8	900	4
10	720	5
12	600	1 or 2
14	514.3	7
16	450	4
18	400	3 and so on

Not only does this slipmeter permit of very accurate tests but it also saves time. In testing an induction motor with a speed counter, an attempt is generally made to keep the load constant for one minute. During this time, the voltage or the periodicity may vary and the load is sure to change unless such elaborate apparatus is employed as to make it impractical for everyday use. The volt, ampere and watt readings may, or may not, be taken at an average torque and the measured speed may, or may not, correspond to said readings. Furthermore, if the speed counter accuracy as referred to the rev. per min. is satisfactory, say 1 per cent, it nevertheless represents a large slip speed error corresponding to about 20 per cent for a 5 per cent slip, to 100 per cent for a 1 per cent slip, and so on. When using the slipmeter, readings of volts, amperes, watts, torque and speed are all taken simultaneously at the instant when the stroboscopic image becomes stationary for any particular setting of the brake; they are all exactly coordinate and the results incomparably more accurate. The slipmeter may be used to measure the slip of the smallest motors without vitiating the results because its use puts no load whatsoever on the machine.

When the test is made on a circuit, the periodicity of which is known to be practically constant, it is not necessary to use a frequency meter, but for particularly accurate work or where the line frequency is subject to material variation, frequency readings should be taken simultaneously with those already mentioned. A convenient form of wide range frequency meter consists of a synchronous motor adapted to operate satisfactorily over a wide range of periodicities coupled to a tachometer of the magneto type used in conjunction with a voltmeter scaled to read direct in cycles per second.

The Instantaneous Stroboscopic Speed Measuring Device permits the rate of revolution of any motor to be determined on the instant without putting any load on the machine whatsoever. It is intended for use in testing fractional horse power motors with any kind of a speed-torque characteristic. This apparatus consists of an adjustable-speed d-c. motor driving a magneto and a disk provided with one or more radial slots. The magneto cooperates with a voltmeter scaled to read direct in rev. per min. and the disk cooperates with a stationary shield provided with a single slot. This shield is so located that each disk slot coincides with the shield slot at one point of each revolution of the disk.

In making use of the apparatus, a geometrical figure is painted on one end of the shaft of the motor under test, or in case the shaft diameter is very small, a disk is firmly attached to the shaft, and observed through the stationary slot in the shield or illuminated by means of light flashes projected onto the shaft figure through the slot in question. The speed of the d-c. motor is then adjusted until the shaft figure appears stationary, when the voltmeter will show the test motor speed or a known multiple thereof.

It is best to select a shaft figure with a single element, and a single, segment-shaped spoke is generally used. The adjustable-speed motor is operated at 500 to 2000 rev. per min. being controlled in part by voltage and in part by field regulation, and drives the magneto direct. The voltmeter connected to the latter reads from 500 to 2000 rev. per min. The motor is geared 1:1 to the slotted disk and the stationary shield is supported by one of the bearings of the countershaft on which the revolving disk and its gear wheel are carried. The countershaft bearings are mounted on top of the d-c. motor. The revolving disk comprises two parts of the same outer diameter. One of these parts is provided with four equidistant radial slots and so keyed onto the countershaft as to make the disk slots coincide with open spaces between the spokes of the gear wheel keyed to the same shaft. The other part is provided with four equidistant slots to match the foregoing and with a fifth located midway between two of the four equidistant ones. This second part can be rotated about the shaft through 45 degrees. In one end position all four slots of both disks coincide and the result is a four-slot disk. In the other end position, the odd slot of one part coincides with one of the slots on the other part and the result is a one-slot disc. The two parts of the revolving disk are held in any desired relative position by means of screws.

Using the one-slot disk setting and a disk motor speed range of 500 to 2000 rev. per min., the number of flashes per minute can be varied from 500 to 2000. Test motor speeds of 500 to 2000 rev. per min. can then be measured by adjusting the speed of the disk motor to produce the lowest speed, single stroboscopic image of the shaft figure. Under these conditions, the voltmeter will read direct in test motor rev. per min. By adjusting the disk motor speed to produce the lowest speed, double stroboscopic image, the voltmeter readings will record double the test motor speeds and test motor speeds of 250 to 1000 rev. per min. are thus covered.

Using the four-slot setting, the number of flashes for the same disk motor speed range can be carried from 2000 to 8000 per minute and test motor speeds of 2000 to 8000 rev. per min. measured by producing the lowest speed, single stroboscopic image of the shaft figure. In this case, the voltmeter reading must be multiplied by four in order to find the test motor speed.

If a range of 250 to 4000 is sufficient, then a one- and a two-slot disk is used, the change from one number to the other being made as in the case of the one- and the four-slot combination. For a two-slot disk, the voltmeter reading multiplier is two. It is of course easy to so arrange the two part disk that 1, 2 and 4 slot disks can be produced by suitably displacing the two parts.

The lower range limit can be reduced to 166.6 test-motor rev. per min. for 500 rev. per min. of the disk motor by adjusting for the lowest speed, triple stroboscopic image in which case the voltmeter reading must be multiplied by one-third to find the test-motor speed.

A tachometer of the magneto type which is regularly calibrated can be relied upon to give accurate enough results for most purposes over a range of 500 to 2000 magneto rev. per min., and readings may even be taken at less than 500 without fear of serious error. This little device therefore easily covers a test-motor speed range of 166 to 8000 rev. per min. and can be used to measure even lower speeds.

A possibility of error lies in the fact that single, double and triple stroboscopic images appear at several speeds, but these differ so greatly that a glance at the pulley of the test motor is in most cases sufficient to gage the order of magnitude of the speed being measured and to make sure that the stroboscopic image is secured at the lowest speed at which this image may be seen. The single spoke when viewed for instance by 500 flashes per minute is stationary and single at 500, 1000, 1500, 2000 rev. per min., stationary and double at 250, 750, 1250 rev. per min., and stationary and triple at 166.6, 333.3, 666.6 rev. per min., so that it is not very difficult to recognize the lowest speed of any series. Should confusion arise on this point it can be readily recognized and rectified when the speed curve is plotted.

ILLUMINATION ITEMS

By the Lighting and Illumination Committee

THE FOOT-CANDLE METER ADAPTED TO AUTOMOBILE HEADLIGHT TESTS

A number of states, particularly the more densely populated ones having complicated traffic problems, have automobile headlight legislation which specifies maximum and minimum candle power values at various angles, in order to eliminate objectionable glare and provide adequate road illumination. The ordinary photometric equipment available for making tests of this kind in the laboratory is usually very cumbersome and expensive. At the same time, many of the companies manufacturing and handling headlighting equipment have use for a portable and inexpensive photometric instrument enabling them to make fairly accurate candle power measurements under factory or service conditions. A number of devices is being marketed, suitable for this purpose. Of these the simplest and least expensive is the foot-candle meter. As commonly employed for industrial and similar commercial purposes it is graduated for illumination values somewhat higher than the minimum values ordinarily measured with automobile headlighting equipment. The regular foot-candle meter may, however, be simply and easily adapted to this special work by the addition of a 1/100 point on the voltmeter scale as shown in Fig. 1, thereby permitting of readings as low as 100 candle power at 100 feet ahead of the car.

The explanation of the use of the foot-candle meter given in the book of instructions accompanying will doubtless eliminate all difficulty in its use. A number of foot-candle meters calibrated in this manner have been in use for some time with automobile and brass lamp manufacturers and are giving very satisfactory service.

In order to measure the candle power directed at a given angle from the headlights, it is merely necessary to hold the foot-candle meter with its face in a plane, normal to the beam at that point. With the voltmeter pointer set at the full scale arrow, the point at which the background and translucent spot appear equally bright will indicate the illumination received in foot-candles as read from the scale. With a voltmeter pointer set at 1/10 or 1/100 scale, the values of illumination will be 1/10 or 1/100 respectively of the

Fig. 1—With the Voltmeter Needle on the 1/100 Scale, at a Distance of 100 Ft. a Reading of 5 Foot-Candles Indicates an Illumination of 500 Candle Power in that Direction. This Scale is Most Useful in a Range from 200 to 2000 Candle Power

foot-candles indicated on the scale. The candle power in that direction will then be equal to the illumination value in foot-candles, multiplied by the square of the distance; for example, at 100 feet the multiplying factor would be 10,000.

It will be noted that the scale of the meter runs from 1 to 40 foot-candles. Hence, at 100 feet, candle power values from 10,000 to 40,000 could be determined with the voltmeter pointer set at the full scale arrow. Inasmuch as it is easier to determine where the translucent spot and the background are equally bright when there are spots darker than the background below this point, it is desirable to use the full scale setting only for values down to, say, two foot-candles, corresponding to a candle power of 20,000 when measured at 100 feet. The 1/10 scale similarly gives a range from 1000 to 40,000 but is most useful in the range from 2000 to 20,000 candle power as measured at 100 feet, that is the indications from 2 to 20 on the meter with the voltmeter pointer set at 1/10 scale. Likewise, with the pointer set at 1/100 scale, the

extreme range provided under these conditions would be from 100 to 4000 candle power, and this scale would be chiefly useful for determination between 200 to 2000.

HIGHER LEVELS OF ILLUMINATION INCREASE ATTRACTIVENESS OF SHOW WINDOWS

The development of the modern show window from a crude, inartistic affair to a display of great beauty and effectiveness has covered a period of a comparatively few years, much the same as the development of the art of electric lighting. In fact it might be said that the advancement of lighting and of show-window display have gone hand in hand. The ineffective means of artificial lighting of a few years ago was a hindrance rather than a help to the efforts to make a display more attractive than it appeared when lighted by natural light. However, efficient high-powered lamps together with a knowledge of the scientific principles of light distribution have eliminated this difficulty and opened up a tremendous field of new possibilities in show window display. Without a doubt modern lighting has been the greatest single factor in advancing the show window to the foremost rank in the list of advertising mediums that the merchant has available.

Fig. 1—"Higher Levels of Illumination Increase Attractiveness of Show Windows"

With the superior lighting equipment available, large department stores have made use of higher levels of illumination in their windows at night with highly satisfactory results from the standpoint of increased sales. The managers of these stores are convinced that an abundance of light adds greatly to the attracting power of windows, but actual test figures as to *how much* this attracting power depends upon the illumination have been lacking. These are now available through a careful investigation arranged a short time ago in Cleveland.

Two display windows of Oppenheim, Collins & Co., located on Euclid Avenue, the main thoroughfare in that city, were used for this purpose. The lighting equipment regularly employed in these windows was used for this investigation.

There were fourteen outlets in each window; by using different combinations of 75, 100, 200, and 300-watt lamps it was possible to obtain illuminations of 15, 40 and 100 foot-candles throughout the test as desired. The persons who stopped in front of each window during the same period of time to look at the display were counted for the different illumination levels used. The test was carefully planned to equalize all factors affecting attracting power except the one of illumination.

42 Per cent Increase in Effectiveness

The data taken during the period of this investigation showed that increasing the illumination in the windows from 15 to 100 foot-candles increased the relative effectiveness of the windows at night by an average of 42 per cent. The effectiveness of the windows under the different levels of illumination was measured by the number of persons who stopped in front of them during the same period of time. Of this total increase, 24 per cent was obtained when the illumination was increased from 15 to 40 foot-candles, and 18 per cent when increased again from 40 to 100 foot-candles. The tests were made between the hours of seven and eleven, on three different nights, during which time approximately 10,000 people passed the store, with an average of one in six stopping to look at one or both windows.

Cost is Justified

Higher levels of illumination cost more, and in order to justify their use they must increase the value of the display area. In Table No. 1 a comparison is made between the approximate cost of illumination and the corresponding attractiveness of the Oppenheim, Collins & Co. windows. If it is assumed, as has been estimated by several of the larger merchants in Cleveland, that a window of this size and location in Cleveland with a 40 foot-candle level of illumination is responsible for about $100 per hour in merchandise sales, it follows that with 100 foot-candles the sales should be increased to $118 per hour. From this table it is seen that for an increase in cost of from 8 cents to 20 cents, or for 12 cents more, per hour, the sales increase is $18.00. From this figure the remarkable effect of higher levels of illumination in increasing the attracting power of a display window can be readily seen in terms of actual dollars and cents profit, which is, after all, the goal of every display window.

TABLE I
Comparative Cost for Different Levels of Illumination in Show Windows at the Oppenheim, Collins & Co.

	Number and energy cost					
Foot-Candles	Size of lamps	Per 1000 hrs. @ 5c. per kw-hr.	*Cost of lamps	†Total per 1000 hr.	Approx. cost per hr.	Relative drawing power of window
15	3 75-watt 4 100-watt	$31.25	$4.33	$35.58	3½c.	100
40	7 200-watt	70.00	9.44	79.44	8c.	124
100	7 300-watt	175.00	23.36	198.36	20c.	142

*$2500 contracts
†Life of Lamp is 1000 hrs.

The Automatic-Start Polyphase Induction Motor

BY JAMES L. HAMILTON
Fellow, A. I. E. E.
Chief Engineer, Century Electric Co., St. Louis, Mo.

A paper presented by the author at the 314th meeting of the American Institute of Electrical Engineers, held in St. Louis, on Oct. 19, 1915, covers the characteristics, electrical and mechanical design of the repulsion-start, single-phase induction motor.

The present paper similarly deals with the automatic-start, polyphase induction motor which has very similar characteristics.

This automatic-start polyphase motor has come into considerable prominence during the last few years. A large number of motors of this type is now being built and placed in service. While there is considerable literature on the subject of induction motors, there is little information available on this type of motor which in reality is a combination of two types of motors, a very high-resistance-rotor induction motor and a low-resistance-rotor induction motor. The motor is converted from a high-resistance-rotor motor at starting, to a low-resistance-rotor motor running by means of an automatic switch.

The objects of this paper are:

1. To set forth the general characteristics of this type of motor as compared with other standard types of motors.

2. To outline a commercially practical method of studying electrical design of existing motors, and predetermining the electrical design of proposed motors.

3. To discuss the mechanical design.

1—General

THE automatic start polyphase induction motor consists of a field or stator of laminated toothed construction having the usual two- or three-phase winding wound thereon and connected to the supply circuit.

The armature or rotor has two windings, one being a progressively wound, low-resistance winding connected to the short-circuiting device, and the other winding being of high-resistance squirrel-cage design.

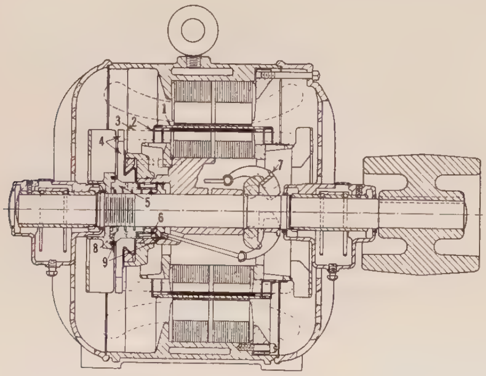


FIG. 1—CROSS SECTION POLYPHASE AUTOMATIC START INDUCTION MOTOR

1. Starting squirrel-cage winding.
2. Heat Insulation.
3. Insulated winding connected to automatic switch.
4. Connector bar.
5. Automatic switch segments, dotted line shows running position.
6. Short-circuiting ring.
7. Governor weights.
8. Governor spring.
9. Packing inclosing switch chamber.

Fig. 1, is a cross sectional view of this type of motor.

The high-resistance winding is usually placed near the surface of the armature, thus giving minimum reactance, and can be proportioned to give high static torque with low static current. The low-resistance winding is usually placed deeper in the armature or beneath the high-resistance winding, and as a result would have high reactance at stand-still due to primary frequency in the armature. However, near synchronism, the frequency in the armature being low, the low-resistance winding also has low reactance; hence gives good running conditions.

The motor starts as an induction motor with only the high-resistance armature winding in circuit, thus permitting low static current and high static torque. After the motor has attained a predetermined speed, the low-resistance winding is short-circuited thus permitting the motor to run with all the rotor copper in circuit, giving small slip, high efficiency and high power factor.

The starting winding can be designed for a maximum static torque for a given current, thus limiting the starting current. The running winding can be designed for the best running conditions when the motor attains speed. This type of motor therefore has the desirable characteristics of a very high-resistance squirrel-cage motor at starting, and the desirable characteristics of a low-resistance squirrel-cage motor when running.

The principle, that polyphase induction motors with the high-resistance rotors start with low current has been known as long as they have been manufactured. The slip-ring, wound-rotor polyphase motor with resistance in the rotor at starting, represents a practical application of this principle. It is only recently, however, that the desirable starting characteristics obtained manually in the slip-ring type of motor, has been made possible by the automatic-start polyphase induction motor.

The very practical and substantial automatic governor and multi-point short-circuiting device developed and used on repulsion-start, single-phase induction motors, have assisted very materially in making the automatic start polyphase motor commercially practical from the very beginning.

Data on Static Torque and Static Current of Motors

Table I gives static torque and static current for various classes of direct-current and alternating-current motors.

As may be observed from these data, approximately the same low static current for a given static torque may be obtained from direct-current motors with starting resistance, with single-phase motors of the repulsion-start type, and polyphase induction motors with manually-operated resistance in the rotor, and with the automatic-start polyphase induction motor.

Experience with motor application on various kinds of drives, shows that a static torque of 175 to 250 per cent of full-load torque is desirable to break the static friction of machinery or apparatus.

The central stations are favorably inclined towards this type of polyphase motor, as it takes a minimum current from the line during the starting period, for a satisfactory static and starting torque. A further advantage of this type of motor over that of a manually started motor, is that the starting currents are predetermined and cannot be changed by an inexperienced operator, as is possible with all manually started apparatus.

This type of motor has high power factor during the starting period, which compares favorably with average power factor obtained with manually started slip-ring motors, and has considerably higher average power factor than is likely to be obtained with manually operated slip-ring motors.

Weight and Size. Weight and size of the automatic-start polyphase induction motor for a given speed and rating, are practically the same as for a direct-current motor, or of a polyphase wound-rotor slip-ring type induction motor.

The squirrel-cage polyphase induction motor, is, of course, somewhat lighter and smaller than the motors mentioned above, due to the absence of slip ring, commutator, or short-circuiting device, but it must be remembered that for squirrel-cage motors of appreciable size, starting compensators are necessary or advisable, which adds considerably to the expense and weight of the combined installation. Troubles incident to the use of compensators in the hands of inexperienced operators, detract somewhat from the apparent simplicity of the squirrel-cage polyphase motor installations.

Field of Application. The automatic-start polyphase induction motor is well adapted for operating various kinds of machinery having considerable inertia, or loads that are difficult to start from rest. It is also well suited for the operation of machinery where the motor would not be under constant supervision of an operator. It can be started on a fuse or other protective device which will protect the motor under operating conditions. A fuse of 120 per cent of rated current of the motor, is usually quite large enough, and a fuse

TABLE I

Class of motor	Kind and size of motor	Static torque in per cent of full-load torque	Static current in per cent of full-load current	Per cent full-load torque for full-load current static	Maximum pulling torque in per cent of full-load torque
Direct current	Small d-c. compound without starter, ¼ h. p. and smaller	350	450	78	275
	Small d-c. shunt without starter, ¼ h. p. and smaller	250	450	55	200
	Large d-c. compound with starter, ½ h. p. and larger	200	170	118	300
	Large d-c. shunt with starter, ½ h. p. and larger	180	170	106	225
Single phase	Single-phase induction motor split-phase start, up to 1/3 h. p.	220	500	44	225
	Single-phase induction motor with clutch and with hand or automatic start, for cutting resistance and reactance in and out of circuit, up to 15 h. p.	140	250	56	150
	Single-phase strongly compensated repulsion motor, up to 15 h. p.	225	500	50	275
	Single-phase weakly compensated repulsion motor, up to 1 h. p.	360	270	133	300
	Single-phase repulsion-start induction motors, 1/10 to ¼ h. p. incl.	450	260	175	225
	Single-phase repulsion-start induction motors, 1/3 h. p. and larger	335	270	125	175
	Single-phase repulsion-start induction motor, 7½ h. p. and larger, with resistance starter	100	170	60	175
	Single-phase repulsion-start induction motor, 7½ h. p. and larger, with compensator starter	100	100	100	175
Polyphase induction	Small two- and three-phase squirrel-cage induction motors, without starter, ¼ h. p. and smaller	215	475	45	225
	Two- and three-phase squirrel-cage induction motors without starter, ½ h. p. to 10 h. p. incl.	225	550	41	225
	Two- and three-phase squirrel-cage induction motors with starting compensator, 7½ h. p. and up	90	300	30	225
	Two- and three-phase automatic-start wound-rotor induction motors, ½ to 10 h. p. incl.	250	260	96	225
	Two- and three-phase automatic-start wound-rotor induction motors, 15 to 50 h. p. incl.	225	260	87	225
	Two- and three-phase wound-rotor induction motors with resistance in rotor for starting, 5 h. p. and up	150	170	90	225

TABLE II

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
From current locus			$\frac{(1)}{(2)}$	440 × (1)	$(2)^2$ × .575	560.6 + (6)	(5) − (7)	$\frac{(8) \times 7.04}{1800}$	$(3)^2$ × 1.14	$\frac{(12)}{(8)}$	(8) − (10)	$\frac{(12)}{(5)}$	$\frac{(12)}{746}$	(11) × 1800
Power comp. of primary current	Primary current I_p	Secondary current I_S	Power factor cos ϕ	Watts-input motor	Watts-primary copper loss	Watts total primary loss	Watts-input to second-ary	Pounds rotor torque	Watts-second-ary copper loss	Rotor speed-% sync.	Motor output watts	Motor efficiency %	Motor output h. p.	Rev. per min.
1.327	5.81	0	22.8	580	19.4	580	.....	.....	......	100	.....	....	.....	1800
6.0	8.0	4.9	75.0	2640	36.8	598	2042	7.98	27.5	98.8	2015	76.3	2.705	1778
14.5	16.0	13.2	90.7	6385	147	708	5677	22.2	199.5	96.6	5477	85.8	7.35	1739
19.2	21.0	18.3	91.4	8455	254	815	7640	29.85	383.0	95.0	7257	85.8	9.73	1720
20.3	22.0	19.3	92.2	8935	279	840	8095	31.6	426.0	94.8	7669	85.8	10.29	1715
27.3	30.0	27.0	91.0	12,000	517	1078	10,922	42.8	833.0	92.2	10,089	84.0	13.50	1660
31.5	35.0	31.9	90.1	13,870	704	1265	12,605	49.3	1165.0	90.8	11,440	82.5	15.36	1634
35.4	40.0	36.6	88.5	15,590	921	1482	14,108	55.2	1530	89.2	12,578	80.7	16.87	1604
42.0	50.0	46.4	85.0	18,600	1440	1901	16,699	65.3	2460	85.4	14,239	76.5	19.09	1537
50.0	65.0	60.6	77.0	22,000	2430	2991	19,009	74.3	4200	77.9	14,809	67.3	19.87	1403
52.2	75.0	70.4	69.6	23,000	3235	3796	19,104	74.7	5670	70.3	13,434	58.4	18.00	1266
50.8	85.0	80.1	59.8	22,350	4160	4721	17,529	68.5	7330	58 2	10,199	45.6	13.68	1047
44.0	90.0	84.9	48.9	19,380	4660	5221	14,159	55.3	8230	45.9	6490	33.5	8.7	825
38.1	95.0	90.0	42.3	16,770	5185	5746	11,024	43.15	9230	16.26	1794	10.7	2.41	293
34.4	97.0	91.5	35.4	15,000	5420	....	9580	37.5	9580	......	.....	....	......	....

as large as 150 per cent of rated current of motor, is never needed to start any load within the capacity of the motor. The motor can therefore be started on a fuse or other protective device which will protect the motor under operating conditions.

II—Electrical Design

Analysis of 10-H. P., 440-Volt, Four-Pole, 60-Cycle Motor

In analyzing a motor, it is well to make accurate load tests so that the load readings may be checked against the calculations, taking sufficient readings to be sure of performance.

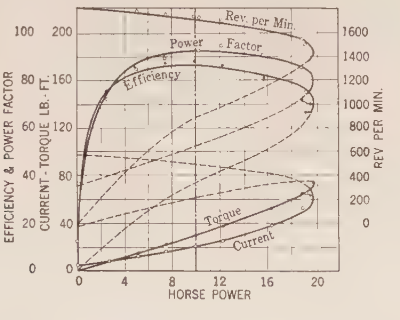


Fig. 2—Performance Curves

Automatic start, three-phase induction motor, 10 h. p., 440 volts, 60 cycles, 4 poles, all copper in armature.

A running idle magnetization test should be made beginning with a voltage somewhat above normal, and reducing the voltage, taking readings at suitable intervals until a voltage is reached where the current begins to increase. A further decrease in voltage causes the motor to stop.

A blocked saturation test is made by short-circuiting the entire rotor by some convenient method, and beginning at a low voltage, reading watts, volts and amperes, taking readings up to full voltage of motor or as near full voltage as is practical.

The results of load tests, running idle magnetization test, and blocked saturation test, are shown in Figs. 2,

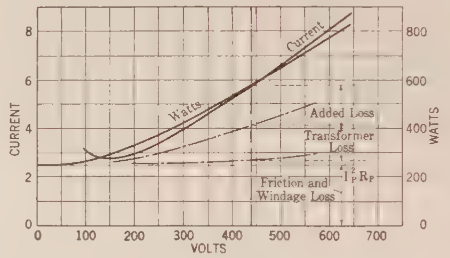


Fig. 3—Idle Magnetization Curves

Automatic start, three-phase induction motor, 10 h. p. 60 cycles, 4 poles, all copper in armature.

3 and 4. The observed points are indicated on Fig. 2 but curves are drawn through the calculated points.

All of the data shown in Figs. 2, 3 and 4 were taken with all of the rotor copper in use and therefore give

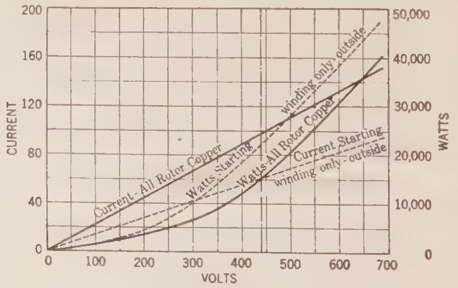


Fig. 4—Blocked Saturation Curves

Automatic start, three-phase induction motor, 10 h. p., 440 volts, 60 cycles, 4 poles.

the performance of the motor when up to speed. Only the starting winding is in service when motor starts and the performance of motor when starting is discussed later in this paper.

Calculations on polyphase motors are, for convenience, usually based on equivalent single-phase current and resistance values. Unless otherwise indicated, all current and resistance values in this paper are of the equivalent single-phase values.

As is well known, the equivalent single-phase current of either a delta- or Y-conected three-phase motor is 1.73 times the current in one line. The equivalent single-phase resistance of either a delta- or Y-connected three-phase motor, is one-half of the ohmic resistance between line leads.

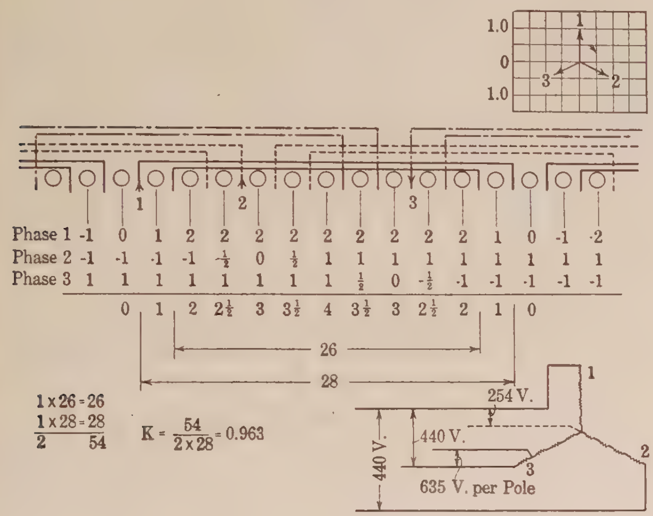


FIG. 5—WINDING CONSTANT CALCULATION

For a condition when phase 1 has maximum current and phases 2 and 3 are equal, each having ½ the current of phase 1.

The equivalent single-phase current of a two-phase motor is obviously the sum of the currents in the two circuits. The equivalent single-phase resistance of a two-phase motor is one-half of the ohmic resistance between the line leads of one phase.

Comparison of design and performance data of single-, two- and three-phase, and direct-current motors, can readily be made when the equivalent single-phase current and resistance values are used.

Motor Data

48 field slots

61 armature slots

Field Winding

Two coils per pole per phase of 21 turns, two No. 13 wires in each coil.

$2 \times 21 = 42$ No. 13 wires in each slot.

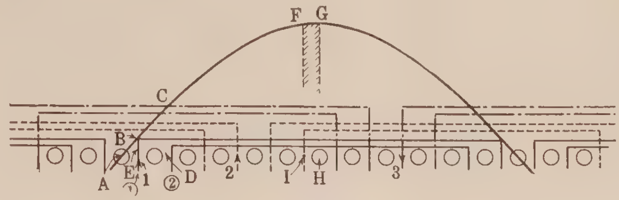


FIG. 6—WINDING CONSTANT CALCULATION BY SINE WAVE METHOD

$$\text{Area of a sine wave} = \int_0^{180} \sin\theta\, d\theta = \Big[-\operatorname{Cos}\theta\Big]_0^{180} = -[\operatorname{Cos} 180° - \operatorname{Cos}] = -[-1-1] = 2$$

$$\text{Area } A\,B\,E = \int_0^{7\frac{1}{2}} \sin\theta\, d\theta = -\Big[\operatorname{Cos}\theta\Big]_0^{7\frac{1}{2}} = -\operatorname{Cos} 7\tfrac{1}{2}° + \operatorname{Cos} 0° = -.99144 + 1.00000 = .00856$$

$$\text{Area } A\,C\,D = \int_0^{22\frac{1}{2}} \sin\theta\, d\theta = -\Big[\operatorname{Cos}\theta\Big]_0^{22\frac{1}{2}} = -\operatorname{Cos} 22\tfrac{1}{2}° + \operatorname{Cos} 0° = -.92388 + 1.00000 = .07612$$

$$\text{Area } F\,G\,H\,I = \int_{82\frac{1}{2}}^{90} \sin\theta\, d\theta = -\Big[\operatorname{Cos}\theta\Big]_{82\frac{1}{2}}^{90} = -\operatorname{Cos} 90° + \operatorname{Cos} 82'2° = -.00000 + .13053 = .13053$$

$$\text{Area coil (1)} = 2 - 2\,[A\,B\,E] = 2 - .01712 = 1.98288$$

$$\text{Area coil (2)} = 2 - 2\,[A\,C\,D] = 2 - .15224 = 1.84776$$

$$3.83064$$

$$K = \frac{3.83064}{2 \times 2} = .9576 \text{ when phase 1 is a maximum, and phase } 2 = 3$$

$$C.\,T. = \frac{.13053 \times 2}{2} = \frac{.261}{2} = .13 \text{ or } 13\% \text{ of the flux per pole is in the central tooth}$$

All poles in series. Motor star-connected.

Resistance of field wire between leads, 1.15 ohms or 0.575 ohms per phase.

Diameter of field punchings = 13 in.

Bore of field punchings = 8 1/4 in.

Net amount of iron 5×0.95 in. = 4.75 in.

Single air gap = 0.028 in.

MAGNETIC CIRCUIT CALCULATIONS

Section	Width in inches	Length in inches along shaft	Area in sq. in.	Flux	Density	Length of circuit	Ampere-turns per inch	Ampere-turns
Field tooth	Min. 0.197 Av. 0.271 Max. 0.345	5 × 0.95 = 4.75	0.936 1.29 1.64	84,000	89,800 65,200 51,200	2.89	7.3	21.1
Field yoke	0.914	4.75	4.34	294,000	67,800	9.46	3.5	33.1
Armature tooth	Min. 0.107 Av. 0.141 Max. 0.175	4.75	0.508 0.669 0.83	66,100	130,200 98,800 79,600	1.75	4.5	78.8
Armature yoke	1.13	4.75	5.36	294,000	54,800	4.23	2.5	10.6
Air gap per tooth	0.461	5.	2.3	84,000	36,450	0.056	add	*639.0
							Total	782.6

*Ampere-turns absorbed in air gaps = $0.313 \times 36{,}450 \times 0.056 = 639$.

Fig. 5 gives the winding diagram and method of figuring the winding constant, which is 0.963.

The winding constant calculation, as will be observed, is based on the theory that the magnetic flux of the various teeth is proportional to the ampere-turns surrounding those teeth.

Fig. 6 gives the method of obtaining the winding constant if we assume sinusoidal flux distribution and determine the winding constant by integration. This method gives a winding constant of 0.957, which is practically the same as the constant obtained by the above method, and will give the flux per pole, and the flux in various parts of the magnetic circuit, of approximately the same value as the first method.

$$\text{Flux per pole} = \frac{63.5 \times 10^8}{4.44 \times 60 \times 42 \times 0.963} = 588{,}000$$

4/28 = 0.142 or 14.2 per cent of flux per pole is in central tooth. Flux in central field tooth = 0.142 × 588,000 = 84,000. Flux in central armature tooth = 48/61 × 84,000 = 66,100.

As one-half of the ampere-turns of the magnetic circuit (at the instant the current in phase No. 1 is at maximum) is produced by phase No. 1, the ampere-turns produced by phase No. 1, is

$$\frac{782.6}{2} = 391.3$$

The magnetizing current required per phase

$$= \frac{391.3 \times .707}{42 \times 2} = 3.29 \text{ amperes, or } 3.29 \times 1.73$$

= 5.7 amperes equivalent single-phase current.

The figure 0.707 is the ratio between the maximum and the effective value of the current, and must be used to get the effective current (or that which is measured by an ammeter).

The figure 42 is the turns per pole per phase, and the figure 2 is used, as the turns of two poles are effective on the magnetic circuit.

The observed magnetizing current $A K$, Fig. 7, is $\sqrt{5.81^2 - 1.33^2} = 5.64$ amperes, which checks very well with the calculated magnetizing current of 5.7.

As the air-gap reluctance is always a very large percentage of the total reluctance of the magnetic circuit, it is well to exercise considerable care in determining the effective area of air gap per field tooth, and also the length of the air gap or clearance.

Experience shows that effective width of air gap per tooth for partially open field and armature slots, is obtained very closely when 35 or 40 per cent of one field slot opening is added to the actual width of the field tooth at the air gap, 37.5 per cent being added in above calculations.

The length of air gap per tooth along the shaft, should be the gross amount of iron in the motor, exclusive of the ventilating duct.

Circle Diagram and Calculation of Performance

The data for obtaining the rotor resistance, running idle and blocked points for circle diagram, are taken from the idle magnetization curve Fig. 3, at 440 volts, and the blocked magnetization curve Fig. 4, at 440 volts, and are calculated as follows:

The resistance of field of 0.575 ohms use in these calculations, was measured with instruments. The resistance of the field can also be obtained of course, by laying out the winding of one pole to scale. With a little time and care, the resistance can be obtained quite accurately by this method and it assists greatly in predetermining the resistance of winding of a proposed motor.

The armature resistance of 1.14 ohms used in these calculations, is obtained as indicated by assuming the one-to-one transformer ratio between field and armature, and therefore dividing the copper loss in the armature under blocked conditions, by the square of the armature current. All of the armature copper is in use when the motor is running and the above armature resistance, therefore, is the resistance of the total armature copper.

The ratio of the total circular mils of all wires in all of the field slots, to the circular mils of all the copper in all of the armature slots, is approximately the same as the ratio of the armature resistance to the field resistance. The above statement is approximately true, as the form factors of field and armature windings of this type of motor are approximately the same and therefore the copper in both field and armature is utilized to the same degree of effectiveness.

This relation affords a very good method of calculating the armature resistance.

The circle diagram Fig. 7 can now be constructed. The running idle point O of the circle diagram is therefore on an arc of 5.81 amperes and at a height of 1.33 amperes.

The blocked point B is on an arc of 97.0 amperes and at a height of 34.4 amperes.

The circle diagram can now be drawn, the center being on a horizontal line passing through the running idle point O, and the circle passing through both the running idle point O and the blocked point B.

The motor resistance now being known, the various losses of the motor running idle, can be separated and

	Watts	Volts	Primary amperes	Cos ϕ	$I_p^2 R_p$	Secondary Amperes	$I_s^2 R_s$	Resistance in ohms	Power component in amperes
Idle	580	440	5.8	0.228	19.4	0	0	0.575	Field 1.33
Blocked	15,000	440	97.0	0.354	5420	91.5	9580	1.14	Arm. 34.4

These data taken with all armature copper in service.

plotted as shown in Fig. 3. The extension of the observed watt curve to zero voltage, gives friction and windage losses.

The free magnetization curves with the losses separated, Fig. 3, gives one at a glance, the various losses in the motor running idle at different voltages on the

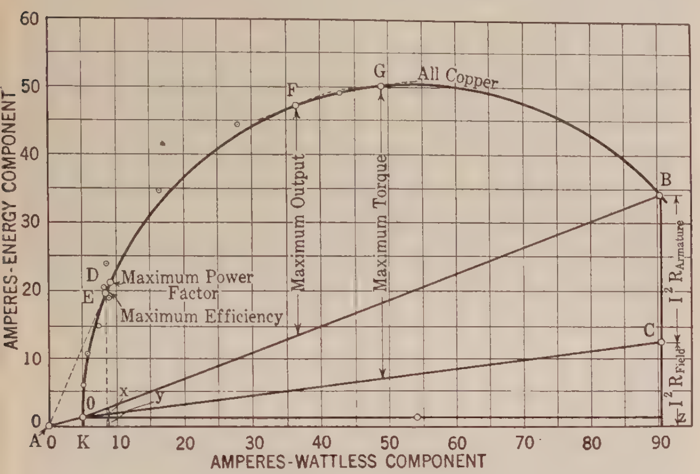


Fig. 7—Circle Diagram

Automatic start, three-phase induction motor, 10 h. p., 440 volts, 60 cycles, 4 poles.

motor, and therefore the action of the motor with different strengths of windings. Lines showing the densities of different parts of the magnetic circuit, may be drawn on this free magnetization curve, if desired.

We may now proceed to calculate the complete performance of this motor as shown in Table II.

Calculations. Columns 1, 2 and 3, as indicated, are taken from the current locus or circle diagram of the motor in the usual way, the primary current for any point on the circle, being measured from A, the secondary current being measured from O, and the power component being the vertical distance from the point on the circle to the line $A\,Z$.

The points on the circle diagram corresponding to maximum efficiency E, maximum power factor D, maximum power F and maximum torque G can be determined graphically as follows:

The maximum power factor is at a point where a line through A is tangent to the circle. The vertical line which gives distances X and Y equal, will intersect the circle at the point of maximum efficiency. In other words, maximum efficiency occurs when the no-load and load losses are equal. The maximum power is at the point of tangency of a line parallel to $O\,B$. The maximum torque is at the point of tangency of a line parallel to $O\,C$. Calculations should be made corresponding to these points.

Item 560.6 at the head of column 7, is the sum of the iron losses (transformer and "added") 310.6 watts and the friction and windage loss of 250 watts.

The other calculations indicated at the top of the various columns are apparent except the Rotor Torque (column 9) formula for which is developed as follows:

W_0 = watts output
W_s = watts input to secondary
S = slip

$$\text{h. p.} = W_0/746 = \frac{2\,\pi\ \text{ft-lb.} \times \text{rev. per min.}}{33{,}000} \quad \text{or}$$

$$\text{ft-lb.} = \frac{W_0 \times 33{,}000}{2\,\pi \times 746 \times \text{rev. per min.}}$$

$$W_0 = W_s\,(1 - S) \text{ and rev. per min.} = \text{Syn. rev. per min.}\ (1 - S)$$

$$\text{ft-lb.} = \frac{33{,}000 \times W_s\,(1 - S)}{2\,\pi \times 746 \times \text{Syn. rev. per min.}\ (1 - S)}$$

$$= 7.04\ \frac{W_s}{\text{Syn. rev. per min.}}$$

The calculated performance curve can now be plotted on the curve sheet, Fig. 2, with the points which were plotted from the observed load test. The curves are drawn through the calculated points. The observed and calculated performances check quite closely, and any slight differences are due mostly to the difficulty in observing with precision the performance of a motor by loading, and also due to the difficulty of eliminating changing temperature conditions while taking the readings for circle diagram calculations and for performance of the motor.

We therefore, now know the performance of the motor at various loads and the various losses in the motor at

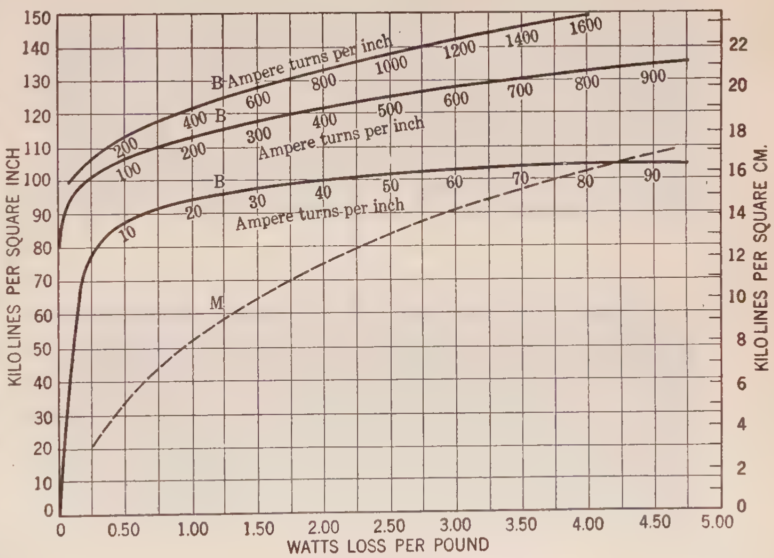


Fig. 8

B Permeability curves for No. 26 electric steel. M Iron Loss curve for No. 26 electric steel, 60 cycle.

those loads, with as great an accuracy as is possible, considering the nature of the problem.

Iron Loss Calculations

The iron loss calculation is given below:

Field teeth			Field yoke			Total calculated loss	Per cent added	Total observed loss
Weight	Loss per lb.	Loss	Weight	Loss per lb.	Loss			
23.55	2.5	58.8	47.35	18.55	87.8	146.6	112	310.6

The weight of the field teeth and field yoke, can be obtained with accuracy by calculating the volume of iron in teeth and yoke, and knowing the magnetic densities in these parts, and taking the loss per pound from a loss curve of the iron used, Fig. 8, the total calculated transformer iron loss of 146.6 is obtained. The total observed loss is taken from idle magnetization curve and is found to be 310.6 which is 112 per cent greater than transformer loss for the motor. This extra iron loss is called "added" iron loss.

Fig. 9 gives two sets of oscillograms taken from this motor. Oscillograms *B* to *F* inclusive were taken by applying a twenty-five-cycle three-phase current (oscillogram *A*) to the motor, reducing the voltage so as

Fig. 9A

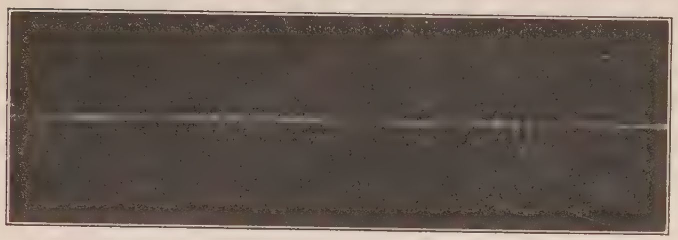


Fig. 9B

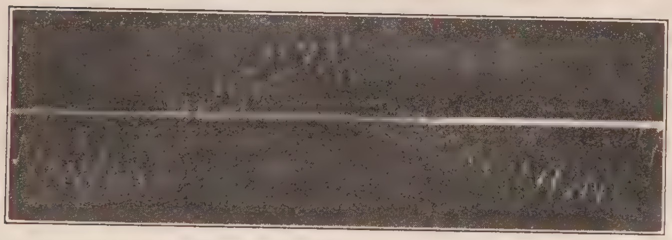


Fig. 9C

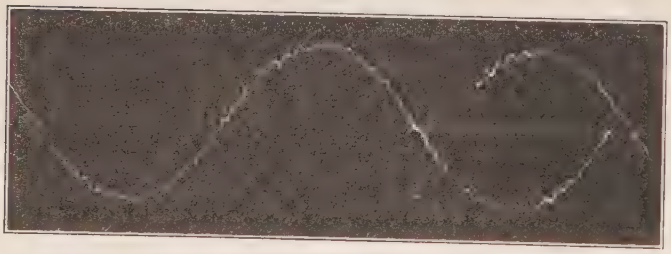


Fig. 9D

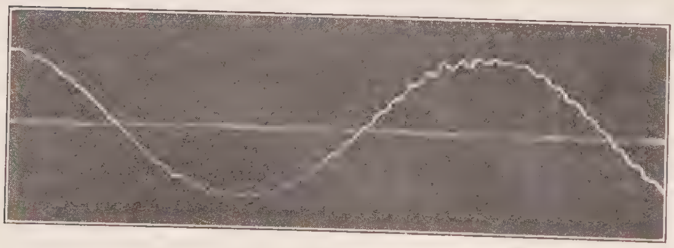


Fig. 9E

Fig. 9F

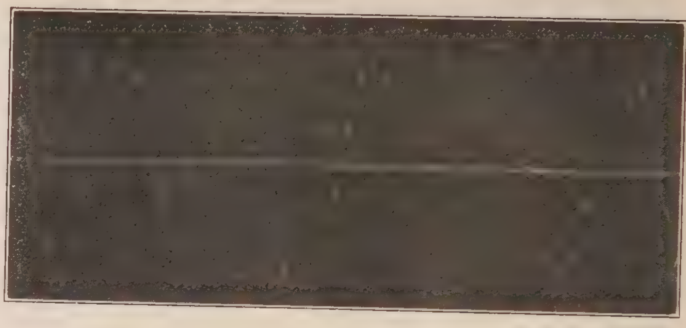


Fig. 9G

Fig. 9H

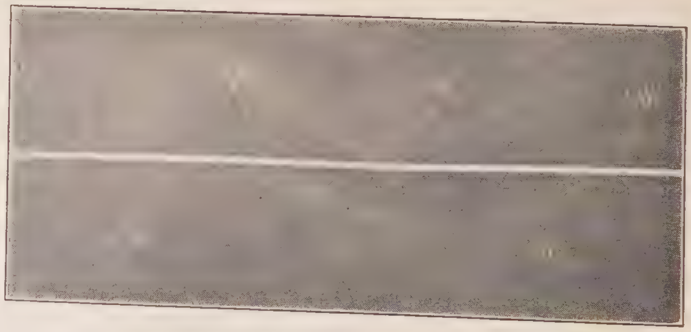


Fig. 9I

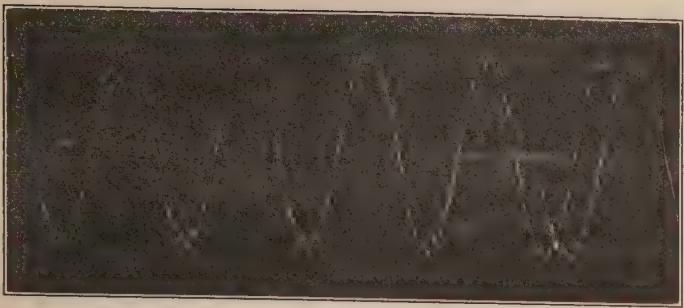


Fig. 9J

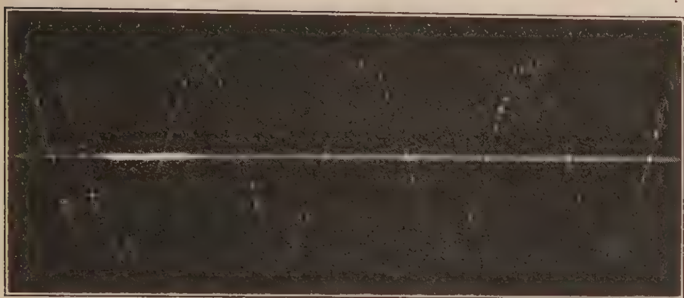


Fig. 9K

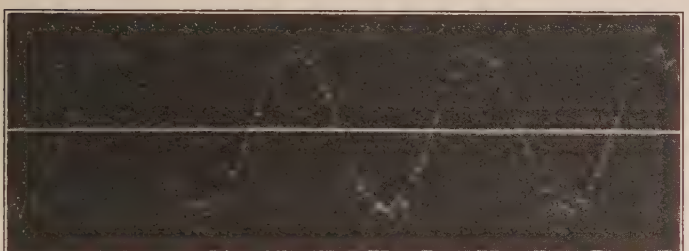


Fig. 9L

to give the same magnetic densities as full voltage on 60 cycles. Oscillograms H to L inclusive were taken by applying a sixty-cycle three-phase current (oscillogram G) at normal voltage to the motor.

Data on these oscillograms are given below:

Oscillogram	Wave data	Approx. amplitude of ripple in per cent of fundamental
A	25-cycle supply voltage	0
B	Flux wave in stator tooth, idle Wave A supplied	18.
C	Flux wave in stator tooth, full load Wave A supplied	23.
D	Flux wave in polar span, idle Wave A supplied	4.2
E	Flux wave in polar span, full load Wave A supplied	4.5
F	Flux wave in yoke, idle Wave A supplied	5.2
G	60-cycle supply voltage	12.5
H	Flux wave in stator tooth, idle Wave G supplied	22.
I	Flux wave in stator tooth, full load Wave G supplied	40.
J	Flux wave in polar span, idle Wave G supplied	4.3
K	Flux wave in polar span, full load Wave G supplied	5.5
L	Flux wave in yoke, idle Wave G supplied	5.4

This motor having 61 rotor slots and being wound four-pole, one half of rotor slot, or 30½, will pass a stator slot in one cycle of line frequency. Therefore, since a complete change of conditions (one cycle) takes place in the stator tooth when the rotor has rotated the pitch of one slot, the frequency of the magnetic ripple in stator teeth should be 30½ times the primary frequency. Likewise the frequency of the magnetic ripple in the polar span and in the yoke should be 30½ times the primary frequency.

These oscillograms have a ripple of 30½ times the fundamental ripple, allowing for slip at full load, thus checking with above calculated frequency.

A study of these oscillograms, shows the following:

1. The rough voltage wave causes larger ripple in stator teeth flux than does the smooth voltage wave, hence, larger added iron loss.
2. The ripple in yoke flux is not greatly affected by the shape of the supply voltage wave.
3. The rough voltage wave at full load causes greater increase in amplitude of ripple over no load in stator tooth flux, than does the smooth wave, hence, causes greater (additional iron loss due to load) loss in teeth.
4. The load losses in stator teeth with smooth voltage wave applied and load losses of yoke with either smooth or rough voltage wave applied, are small.
5. The ripple in magnetic wave over polar span is substantially the same as in the yoke.
6. The per cent added iron loss in the teeth, is very much greater than the per cent added iron loss in the yoke.

Circle Coefficient Calculations

The circle coefficient and maximum power factor of this motor may be calculated from the physical dimensions of the electrical design by Behn-Eschenburg's empirical formula as follows:

$$\sigma = 3/X^2 + \frac{10\,A\,C}{X\,Y\,T} + \frac{5\,A}{L\,i}$$

σ = Circle coefficient
X = The mean number of slots per pole in field and armature
Y = Width of the slot openings in inches
A = Motors single air gap (clearance) in inches
C = Average tooth tip thickness of field and armature in inches
T = Pole pitch in inches
$L\,i$ = Net iron length of the core in inches

For this motor we have

$$\frac{3}{(13.625)^2} + \frac{10 \times 0.028 \times 0.0625}{13.625 \times 0.125 \times 6.475} + \frac{5 \times 0.028}{4.75} =$$

$0.002610 + 0.001587 + 0.029490 = 0.033687$

Since the maximum power factor for a polyphase

motor $= \dfrac{1}{1 + 2 \times \sigma}$ we have $\dfrac{1}{1 + 2 \times 0.0337} = 93.7$ per cent maximum power factor calculated.

This is a fair agreement with the observed maximum power factor of 94.3 for this motor, and calculated power factor from circle diagram of 92.2.

We have now analyzed and calculated the motor completely. We will next show how the various calculations may be made and the performance predetermined for a new or proposed motor.

Predetermining the Performance of a Proposed Motor

Each designer has his own particular method of starting a new electrical design, and if based on correct theory and sufficient data, will lead to substantially the same results in the end.

Fig. 10 gives the total magnetic flux for four- and six-pole, 60-cycle two- and three-phase induction motors

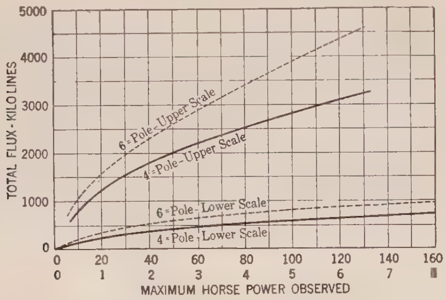


Fig. 10—Flux—Horse Power Curves
Automatic start, three-phase induction motor, 4 and 6 poles, 60 cycles.

for various maximum horse powers and outputs. Data like these, when available, give a very convenient and safe starting point for preliminary design for not only this type of motor, but for any alternating-current induction motor.

The principal factors which may cause a variation in the total magnetic flux for a given horse power, are the armature resistance and leakage reactance, both of which are fairly constant for motors of the same size and general construction.

The number of slots in field and armature should next be decided upon. The number of field slots for a polyphase motor, must, of course, be determined by the different number of poles and phases for which it is desired to wind the motor. To get good results, usually one or two, and often three field punching designs are necessary. Usually one or two armature designs can be found which will work satisfactorily with the various field punching designs required.

In general, either a lesser number or greater number of armature slots than field slots may be used with substantially the same results.

Having decided on the best number of slots in the field and armature, and knowing the number of poles and the voltage of the motor, the number of turns may be calculated from the formula used in analyzing the motor earlier in this paper. Knowing the number of wires in the slot and by estimating the current taken by the motor of the size under consideration, the preliminary size of the field wire can be estimated, allowing 500 to 800 circular mils per ampere. The smaller number of circular mils per ampere should be used only in motors that are especially well ventilated which are usually rotors of comparatively high peripheral speed. In general, it will be found advantageous to work nearer to the upper figure 800 circular mils per ampere, when a large amount of power is to be obtained from a given amount of active iron. Knowing the number of turns and resistance of the field winding, the armature winding and resistance may be calculated as has been outlined.

As this type motor has two distinct armature windings, a starting winding and a winding which is short-circuited when the motor reaches a predetermined speed, both windings must be considered when figuring the armature resistance, as both windings are in service when the motor is running.

The design data of the starting windings and the winding which is short-circuited, are discussed more fully further on in this paper.

Having the magnetic flux per pole, and having determined the field winding, the flux in the various parts of the magnetic circuit may be determined as has been done previously in analyzing this motor. By fixing the magnetic densities in the different parts of the magnetic circuit, the area of the different members can be calculated. Magnetic densities which may be used, depend to a large extent on the quality and kind of sheet steel used. Practically all iron used at the present time in alternating current motors, shows a permeability and watt loss as good as is given in Fig. 8.

With iron of this quality the

	Lines per sq. in.
Field yoke can be worked at	60,000 to 80,000
Field teeth average section can be worked at	80,000 " 110,000
Field teeth minimum section can be worked at	100,000 " 125,000
Armature teeth average section can be worked at	90,000 " 115,000
Armature teeth minimum section can be worked at	100,000 " 135,000
Armature yoke section can be worked at	75,000 " 90,000

for 60-cycle motors.

The preliminary electrical design may now be drawn to scale, starting with either armature diameter or field iron diameter which it is desirable to use. The preliminary design may be out of proportion, that is, if armature diameter selected is too small, the design will call for too much iron along the shaft, in which case a larger field and armature diameter is necessary.

On the other hand, if an armature diameter is selected which is too large, the motor iron along the shaft will

be too short and the motor will be unnecessarily expensive and also have poor characteristics.

The best general proportions as to the relation of polar pitch at the air gap, and the length of iron along the shaft, may be checked by the following observations on this type of motor. The length of iron along the shaft should be 50 per cent to 100 per cent of the polar pitch, 60 per cent to 70 per cent giving the best all around performance, but if the diameter of armature and field punchings is large, the motor will be somewhat more expensive in general to build. If, as is often the case with the larger motors, it is desirable to build four-, six- and eight-pole motors in the same frame, 50 per cent for four-pole motors may be used, which will result in fair characteristics for each of the three motors.

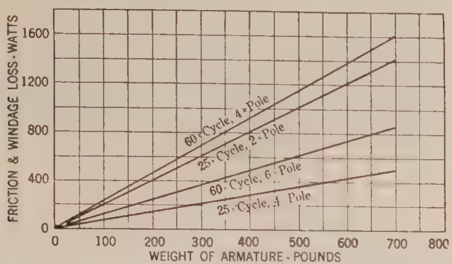


Fig. 11—Friction and Windage Loss Curves

Automatic start, three-phase induction motors, 2 and 4 pole, 25 cycle; 4 and 6 pole, 60 cycle, bronze bearings.

Having made the preliminary design and checked the general proportions, if it is considered advisable, new diameters and length of iron may be determined for the electrical design. It will therefore, usually be safe to proceed with the second design.

The magnetizing current, field and armature copper loss, and iron loss, may now be calculated as was done when analyzing the existing motor. "Added" iron loss can be estimated with a fair degree of accuracy from data on existing motors. If these data are not available, adding 100 per cent to the transformer loss will, in general, give fairly close results. The friction and windage losses depend, of course, on the air friction of winding on the weight of armature, size of shaft, size of bearing and lubrication.

Fig. 11 gives the data for obtaining the friction and windage losses of armatures of various weights and of various speeds. Knowing the idle losses, the running point of the circle diagram can be plotted. The height of the running idle point being the energy component necessary to give the idle watts taken by the motor.

The circle coefficient, the maximum power factor, and hence the diameter of the circle may now be calculated from the physical dimensions of the electrical design as was done previously, the circle being drawn as before through the running idle point and tangential to the maximum power factor line, the blocked point not as yet having been determined.

The complete performance may therefore now be calculated as was previously done.

Having a complete layout and calculated performance of the proposed design, the different factors, such as, slip, power factor, efficiency, etc., may be considered in detail and detail modifications made, and the effect on the other factors noted with comparative ease. The maximum efficiency can be made to occur at either less or greater than full load by arranging the iron loss and copper loss accordingly. The point at which the maximum power factor occurs, can within certain limits, also be regulated by modification of the design.

In designing the automatic-start type of induction motor, of course, special attention must be given to getting a fairly good start and keeping the current at standstill and when governor operates at proper figures. This necessitates using an armature with a running resistance which is not too low. This will be more fully discussed later.

The temperature rise of the different parts of the motor, depends, of course, to a large extent on the mechanical design, construction and ventilation, whether natural or by forced draft as with a definite fanning action. Fig. 12 will serve to indicate, in general, how much the temperature of the motor may be expected to rise above the surrounding air.

The velocity of air in feet per minute, given on the curves, shows the approximate amount of air which, if blown over the surface of an enclosed frame of same size and rating, will give the same temperature rise.

Discussion of Starting Characteristics

The starting characteristics of this type motor, depend very largely on the design of the starting winding

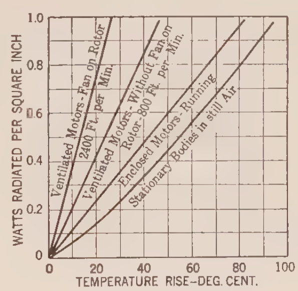


Fig. 12

Fig. 13 gives typical starting characteristics for a motor of this kind.

These curves are plotted from observed readings on the motor. The curves may also be calculated from the circle diagram on the starting winding, similarly to the calculations of the motor under running conditions and with all the rotor copper.

As may be noted from Fig. 13, this motor has a static torque of 75½ lb-ft., or 250 per cent of full load torque. With a static current of 65 amperes which is 300 per cent of full load current.

The N. E. L. A. rules state that 75 per cent of the locked rotor current is considered as the starting cur-

rent, in which case the so-called starting current of this motor would be 75 per cent of 65 amperes, or 49 amperes, or 230 per cent of full-load current.

The following running idle and static readings were taken from this motor. The starting winding only was in rotor circuit when static readings were taken.

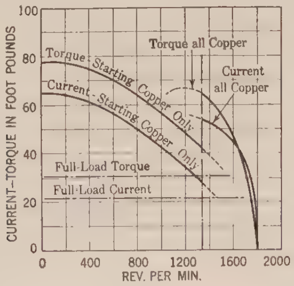


FIG. 13—STARTING CHARACTERISTICS
Automatic start, three-phase induction motor, 10 h. p., 440 volts, 60 cycle, 4 pole, starting copper outside main winding.

The starting squirrel-cage winding in this motor, was placed outside of the main winding, which position gives a maximum static torque for given static current.

Fig. 14 gives three circle diagrams for this motor with three conditions of rotor as follows:

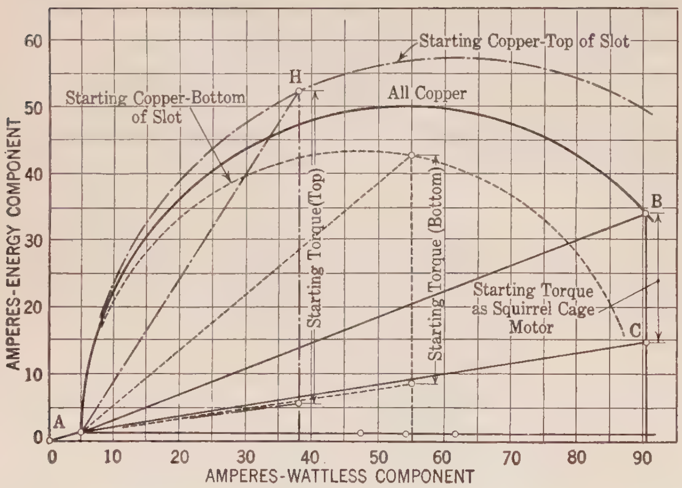


FIG. 14

1. Total copper
2. Starting copper at the bottom of slots
3. Starting copper at top of slots.

The latter circle was constructed from readings given above. These circle diagrams show clearly the advantage of placing starting winding at top of slots, both as regards the power factor of the starting current and the starting torque.

From the above static reading, the resistance of the starting winding is calculated to be as indicated 5.23 ohms. This corresponds with the armature resistance of all the copper, of 1.14 ohms, and the field resistance of 0.575 ohms. This gives ratio of armature resistance (all copper) to field resistance of 1.14/0.575, or approximately two times the field resistance.

The starting copper has resistance of 5.23 or approximately nine times the field resistance. The starting copper has 5.23/1.14, or approximately four and one-half times the armature resistance with all the copper in service.

In general, these proportions of starting winding resistance, running resistance, and field resistance, give the best starting and running conditions.

As may be noted from Fig. 13, the starting winding has the maximum torque at or near standstill. Hence, it has maximum torque efficiency at standstill.

If a starting winding of higher resistance is used so as to get lower static current, the amount of load the motor can bring to speed will be reduced. It is always desirable to have no greater current flow when governor short-circuits the running winding, than flowed at the moment of connecting motor to line.

It will be observed from the above curves, that the motor brought to speed a load of 135 per cent of full load which is ample for any load within capacity of the motor. It is therefore apparent that a starting winding with lower resistance, would have greater static current without any compensating advantage.

The starting squirrel-cage winding is similar to any satisfactory squirrel-cage winding. As this winding must dissipate considerable heat as the motor starts and comes to speed, it should be well ventilated and insulated with sufficient heat-insulating material, from the windings connected to commutator, in order that very little of the heat from the starting winding will reach the insulated winding.

It is interesting to compare the observed static torque and the calculated static torque. The calculated static torque is obtained as follows:

$$\frac{18970 \times 7.04}{1800} = 74\tfrac{1}{2} \text{ lb-ft.}$$

The observed static torque with starting winding, was 70 to 78 lb-ft. depending on the temperature.

These calculated and observed results should, of course, check quite closely with the readings taken with a rotor of the same temperature, and making due allowance for friction in the bearings.

It is interesting to note that the ratio with motor

Observed readings	Watts	Volts	Amperes	Cos ϕ	$I_p^2\ R_p$	Amperes-sec.	$I_s^2\ R_s$	Resistance ohms	Power comp.	Static torque lb-ft.
Idle	580	437	5.81	0.228	19.4	...	....	0.575	1.33	....
Blocked	21,400	440	65	0.75	2430	*61	18,970	5.23	48.8	75½

*Obtained from circle diagram Fig. 14.

blocked, of watts armature loss to total watts input to motor, is 18970/21400 = 89 per cent.

Therefore, 89 per cent of total energy taken by the motor is effective in producing torque.

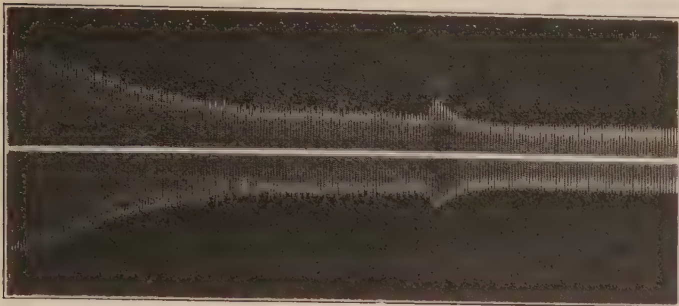


Fig. 15A

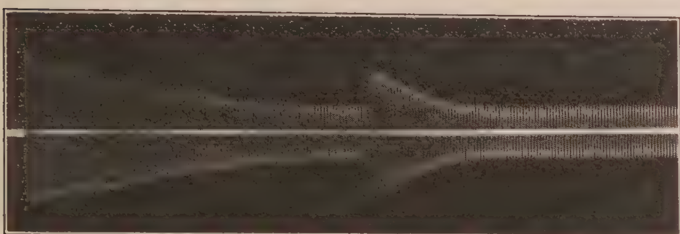


Fig. 15B

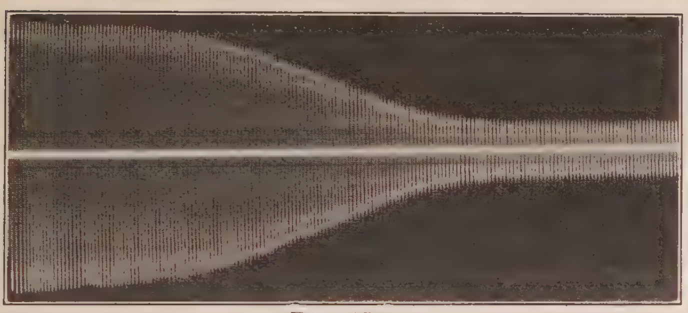


Fig. 15C

Fig. 15 gives oscillograms of starting current of three different types of motors. The following data taken from these oscillograms, give some interesting comparisons.

Oscillogram	Motor data	Amperes			
		Static	When gov. operates	Full load: Per line	Full load: Equivalent single phase
A	10-h. p., 440-volt, 60-cycle four-pole single-phase repulsion start induction motor................	72	42	24	24
B	10-h. p., 440-volt. 60-cycle four-pole three-phase automatic-start induction motor...........	60	54	12.5	21.5
C	10-h. p., 440-volt, 60-cycle four-pole three-phase squirrel-cage induction motor................ (without compensator)	105	..	12.5	21.5

The point at which the governor acts on the single-phase and on the automatic start polyphase motor, is apparent.

III—Mechanical Design

The success and dependability of this type of motor has been due to a very large extent to the fact that the short-circuiting device has been developed so that it is entirely dependable even under adverse conditions.

The automatic governor which works on the centrifugal principle, is so designed that the short-circuiting action takes place instantly, even though the motor is accelerating very slowly.

The switch which closes the low-resistance winding, consists of a very large number of segments, and therefore, each segment has a very small amount of current to carry. The quick action of the switch, together with the large number of segments in the switch, assures smooth and efficient action of the starting switch for a very long period.

The chamber where the switch closes the circuit is made practically dust-proof, so no trouble is experienced in the action of the switch even when the motor is operating under dirty and unfavorable conditions.

It is well known among designers, that a rigid frame and strong shaft is as essential to a quiet starting and quiet running motor, as is a good electrical design.

Use of fans in this type of motor, as in others, helps materially to prevent hot spots and to keep the motor cool.

Fig. 1 shows a cross-sectional view of automatic-start polyphase induction motor. This view shows the arrangement and construction of the automatic switch.

Summary

The starting efficiency of the automatic-start polyphase induction motor, is substantially the same as for shunt or compound-wound direct-current, the polyphase-slip-ring motor with resistance in rotor starting, and the single-phase repulsion-start induction motor.

This type of motor in all sizes may be started by closing the switch without the use of a starter of any kind as it takes static current of not over 300 per cent of full-load current and has static torque of about 250 per cent of full-load torque.

This type of motor is simpler to install and operate than the direct-current motor with starter, or the polyphase squirrel-cage motor with compensator, or the polyphase wound-rotor-slip-ring type of motor with resistance in rotor at starting.

A commercial and practical method has been outlined for analyzing existing motors or predetermining the performance of new motors.

The excellent performance and the comparative freedom from trouble and annoyance of the automatic short-circuiting devices, has established this type of motor in the polyphase motor field.

Discussion

A. C. Lanier: Mr. Hamilton introduces a motor which resembles closely in its automatic operation the combined action of the standard moderate-slip induction motor and its controller. The automatic-start polyphase induction motor runs at moderately low slip, yet it starts with high torque and reasonably small starting current. Though the starting current and starting torque are somewhat higher than usual in the wound-rotor type of induction motor with its controller, the performance of this motor during acceleration and at running speed is not unlike the former in many respects. The torque, as indicated in Fig. 13 of the author's paper remains high during the entire accelerating period, at no point dropping below 140 per cent of the normal running torque. Such a motor should be suitable for many applications where the ordinary cage-wound motor with compensator would result in sluggish acceleration and a heavy draft of line current, with consequent impairment of voltage regulation, and where intelligent care and attention of operative is lacking, *i. e.*, where a "fool proof" equipment is desired.

Attempts to secure in a single unit similar combined accelerating and running characteristics, either by hand, automatic, or inherent change in motor characteristics during the period of acceleration, have been made before. The wound-rotor motor, for example, with starting resistance built into the rotor and arranged to be short-circuited by steps during acceleration, has been exploited commercially.

A type of motor in which changes are effected in its inherent characteristics during acceleration has also been suggested. This motor has a squirrel-cage rotor with deep, narrow, slots and bars, the latter of large section, such as would give to the rotor

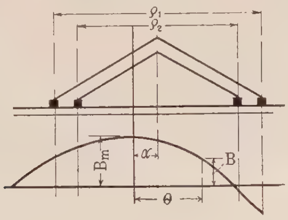


FIG. 1

relatively low resistance. At standstill, due to the high inductance of the rotor winding, the variation of slot-leakage flux would cause considerable current distortion in the rotor bars and consequent increase in the effective rotor resistance, with a resulting increase in starting torque; while at running slips this distortional effect would be small and the rotor resistance equal approximately to its ohmic resistance. Between standstill and running speed, the distortional effect will decrease, thus merging the starting into the running characteristics.

The double-winding rotor has, however, despite its increased cost, and somewhat greater mechanical complexity, the advantage of allowing the designer to determine starting and running performance separately without very appreciable departure from normal design, and without having the demands of one compromised by those of the other.

The author has given in his paper detailed calculations and dimensions for one size of motor, and has indicated very clearly his procedure in design. In discussing the author's procedure it will be the speaker's purpose to indicate other, though not necessarily better, ways of approaching the same problem.

The author gives two methods of determining the winding factor which give results that are in fair agreement. Another method, possibly somewhat simpler than either of those shown might be used. The two coils per pole in the same phase of the stator winding are, for the motor under discussion, co-axial as shown in Fig. 1. There is, therefore, no phase displacement between the e. m. f.s generated in these two coils so that their e. m. f.s combine algebraically. The "breadth" of "belt" factor is, therefore, equal to one. There is, however, a decrease in the generated e. m. f. in each coil due to the short-chording of the coil, the chording of the two coils being unequal in this case. The "pitch" factors are both less than unity and unequal. The average of the two pitch factors of the two coils would be the resulting winding factor.

The pitch factor may be shown to be equal to $\sin \rho/2$, where ρ is the coil throw in electrical radians or electrical degrees. This is true for sinusoidal flux distribution in the air gap; for non-sinusoidal distributions $\sin \rho/2$ is the pitch factor for the fundamental e. m. f. wave, and $\sin \dfrac{m\,\rho}{2}$ (or $\cos \dfrac{n\,(180-\rho)}{2}$ a more convenient form) for the nth harmonic wave. To justify this relationship for the pitch factor, assume that the flux distribution in the gap is a cosine function of the maximum flux density, B_m, of the wave, as indicated in Fig. 1; then B, the instantaneous flux density at any point displaced θ radians from the axis of the flux wave is $B = B_m \cos \theta$ and the value, at any instant, of the flux embraced by the coil 1, whose axis is displaced α radians from the flux axis and has a throw ρ_1 in electrical radians is

$$\varphi_1 = \frac{\lambda\, l^2}{\pi} \int_{-(\rho_1/2-\alpha)}^{\rho_1/2+\alpha} B_m \cos \theta \, d\,\theta$$

$$= \frac{2\,\lambda\, l}{\pi} B_m \cos \alpha \sin \rho_1/2$$

where λ is the pole pitch and l the core length in linear measure. The value of flux, per pole, is

$$\Phi = \frac{2\,\lambda\, l}{\pi} B_m$$

so that

$$\varphi_1 = \Phi \cos \alpha \sin \rho_1/2$$

The instataneous value of e. m. f. e_1 generated in coil 1 is

$$e_1 = -N_1 \frac{\alpha\, \varphi}{d\,t} 10^{-8}$$

$$= -N_1 \Phi \sin \rho/2 \frac{d}{d\,t} \cos \alpha\, 10^{-8}$$

$$= 2\,\pi\, f\, N_1 \Phi \sin \rho_1/2 \sin \alpha\, 10^{-8}$$

and for coil 2

$$e_2 = 2\,\pi\, f\, N_2 \Phi \sin \rho_2/2 \sin \alpha\, 10^{-8}$$

and the e. m. f. of the two coils in series, which are in phase, is

$$e = e_1 + e_2$$

$$= 2\,\pi\, f\, N\, \Phi \sin \alpha \left[\frac{\sin \rho_1/2 + \sin \rho_2/2}{2} \right] 10^{-8}$$

where

where $N = N_1 + N_2$ and $\dfrac{\sin \rho_1/2 + \sin \rho_2/2}{2}$, the average pitch factor.

In this particular motor $\rho_1 = 165$ deg., since coil 1 is chorded one slot, or 15 deg., and $\rho_2 = 135$ deg., so that the pitch factor k_p, is

$$k_p = 1/2\,[\sin 165/2 + \sin 135/2]$$
$$= 1/2\,[0.9914 + 0.9239]$$
$$= 0.9577$$

This agrees with the winding factor which the author obtained by his second method.

In the calculation of air-gap reluctance the author has added to the stator tooth tip width a percentage of the stator slot opening to account for the fringing of flux at the edges of the tooth. This short cut method should give fairly reliable results when

checked by tests, if the ratio of slot opening to single air gap does not vary widely for the different machines considered. Where any radical departure in design is made, however, such as a change from the partially closed to the open stator slot, considerable error may result from the use of empirical methods, unless dependable experimental data are available from which to determine the percentage increase of the tooth width for this condition. It is desirable, therefore, to be able to determine the fringing factor on the basis of the dimensional relationships upon which it depends.

It was shown by Mr. F. W. Carter that the reduction in effective gap area (or increase in effective gap length), due to the presence of slot openings, is expressable in terms of the ratio of slot opening to single air gap, and the ratio of tooth-pitch to tooth tip width. The results of Mr. Carter's analysis may be plotted in curve form, as indicated in Fig. 2, and the gap-correction factors taken from these curves very quickly, when ratio of slot opening to single air gap, and that of tooth tip width to tooth pitch are known. These curves give values of correction coefficient for a single-slotted member; when both rotor and stator are slotted, the correction due to the double slotting must be made. Professor C. A. Adams has shown that the product of the two correction factors, one calculated on the assumption that the stator is slotted and the rotor smooth, and the other that the rotor is slotted and the stator smooth, gives with close approximation the combined slot correction factor. The accurate

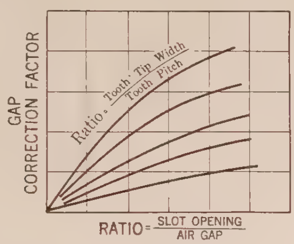


FIG. 2

determination of the effective gap area should account, further, for the effects due to the fringing of flux around the core ends and between the sides of ventilating ducts from stator to rotor; though with the small air gaps used in induction motors, these latter corrections are, in general, small.

In the calculation of the tooth-magnetizing ampere-turns, the author has used the mean value, determined by Simpson's rule, of the ampere turns per inch length of path for the densities at the top, middle, and bottom sections of the teeth: this method is probably the best one for accurate results. Where the apparent density at any tooth section exceeds 110,000 lines per square inch, however, the flux in the air path through the slots, vent ducts, and interlamellar space, paralleling the iron path through the teeth, becomes appreciable in amount; in such cases the "actual" tooth density, that determined from the flux in the tooth iron itself (a value smaller than the "apparent" density) should be used. For machines with parallel-sided slots, some engineers determine the magnetizing ampere turns for the teeth from the density at a tooth section, one third tooth-length from the minimum section. The speaker has used this shorter method and has found it to give results that check satisfactorily with test values.

Two methods are in general use for determining the performance of induction motors from simple shop test data—the measured stator-winding resistance, the running-light and the blocked-rotor tests—or for pre-determining performance from calculated stator and rotor resistances and reactances and the exciting admittance. One, the analytical method, is based on the "equivalent circuit" diagram shown in Fig. 3. The series parallel grouping of resistances and reactances, reduced to a one-to-one transformer ratio, are combined in steps, beginning with the secondary, thus securing the equivalent admittance of the total circuit and of the different parts thereof. In this diagram we may use, for the polyphase motor either the equivalent single-phase values of motor constants or the values per phase. From these admittances, starting with the total admittance and the primary impressed voltage, the current-voltage relationships in all parts of the circuit may be determined for different assumed values of slip, and from them the power, torque, power factor, efficiency and other desired quantities.

The other general method of determining motor performance is graphical, using one of the several so-called "circle diagrams." The simplest of these, frequently referred to as the "Heyland-Behrend" diagram, is based on the equivalent electric circuit shown in Fig. 4. It assumes that the effective value of the potential difference impressed upon the exciting admittance is constant, and that the rotational losses are constant and are

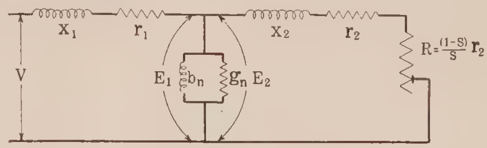


FIG. 3

supplied electrically through the primary. This approximate diagram gives dependable results for polyphase motors of normal design above five h. p. capacity. The author uses this diagram and his results are in reasonably close agreement with those obtained from running test and with values obtainable by the analytical method; the latter are, however, slightly nearer the running test values, particularly on light loads, and the method yields, in general, somewhat more dependable results.

Modification of the original circle diagram, advocated by Bragstad, Ossana and others, though introducing further complexity in construction, lead to a higher degree of accuracy. Though the gains in accuracy may not justify the greater difficulty in construction of the more accurate diagrams for large power motors, yet in small machines, fractional horse power motors in particular, the approximations of the simple circle diagrams lead to excessive errors in determined performance, and render the use of a more accurate method imperative.

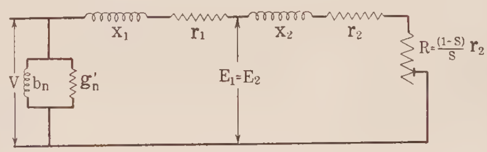


FIG. 4

The oscillograms illustrative of pulsations in tooth flux and "ripples" in the total polar-flux wave are interesting and are suggestive of important effects upon the performance of the motor. These high-frequency flux variations, due chiefly to cyclic changes in the reluctance of the magnetic circuit, are responsible for a part of the losses in the motor. As is well known, the total losses of the induction motor on load exceed considerably the sum of the so-called "transformer" iron losses (eddy current and hysteric losses due to the harmonic variations of the flux, common to both stator and rotor, at fundamental frequency) and the copper losses in primary and secondary, based on ohmic resistance of the windings. These excess losses, frequently referred to as "added losses" are varied in nature and source; usually they are traceable to current or flux distortion or to high frequency pulsations, directly associated, in many instances, with dimensional relationships in the machine.

The "added losses", as to character and cause, may be classified as follows

1. Extra iron loss at fundamental frequency, due to non-sinusoidal flux distribution, constriction of flux behind the slots, the presence of end plates, bolts, solid frame structure, etc.

2. Iron loss, due to slot leakage fluxes at fundamental frequency.

3. Eddy current losses in the copper, due to the leakage flux variations at fundamental frequencies.

4. "Surface losses," iron losses at and near the surface of one member, caused by high-frequency variation of flux density, due to the motion of an opposed plotted member.

5. "Tooth pulsation losses," iron losses in the teeth, caused by the variation at high frequency of the tooth flux densities; these high frequency flux pulsations are caused by cyclic variations in reluctance (of teeth and gap chiefly) due to relative motion of double-slotted members. These pulsations are damped by parts of winding surroundings single teeth.

6. Extra copper losses, due to the localized high-frequency currents which damp the tooth pulsations.

7. Losses due to pulsations of magnemotive forces, caused by higher harmonics in the supply voltage (strongly damped).

Relatively slight dimensional changes, such as are frequently made in commercial machines, may increase greatly some of these added losses. The speaker has known of increases of from thirty to forty per cent in measured no-load losses, resulting from such slight and seemingly innocent changes. Sufficient experimental data are not available to give the engineer dependable methods of calculating many of these extra losses, though a number of interesting investigations have been made and some usable results secured. A further extension of our knowledge of these losses is desirable, not only that it may be possible to predetermine them, but also, what is frequently of more importance, that the designer may choose such dimensional relationships as will minimize them.

H. Weichsel: Very shortly after the polyphase motor had been invented it was recognized that the starting performances of these motors are poor when the rotor has low-resistance, and that good starting conditions can be obtained with high-resistance rotor. On the other hand, a high-resistance rotor showed poor running characteristics. It was in the year 1891 that Professor Arnold, the now well known author of the text books on electricity, proposed a rotor with a great number of phases all of which were brought out to slip rings. During the starting period the leads coming from these slip rings were so connected that the e. m. f.s produced in these different phase groups opposed each other. This had a result similar to increasing the rotor resistance. When the machine had come up to speed, the leads coming from the slip rings were regrouped in such a manner that all the e. m. f.s produced in the phase belts were helping each other and were short-circuited in themselves.

Three years later, in the year 1894, Professor Goerges patented a motor which had two three-phase windings on the rotor. These windings were made with different numbers of turns, and were connected in parallel. During starting period the parallel windings produced e. m. f.s which opposed each other, but which were of different magnitude; therefore, a circulating current was set up proportional to the differences in e. m. f. produced in the two windings. For this reason the motor acted like a high-resistance rotor. After the machine had reached approximately normal speed, all windings of this rotor were short-circuited in themselves and the rotor now acted like a rotor with low-resistance winding. The Siemens-Schuckert Company built Professor Goerges' motor and put it on the market with an automatic short-circuiting device. This device was operated by centrifugal force. As soon as the motor had reached a speed near the normal, the centrifugal force of two governor weights was large enough to overpower two springs, and in this manner produced a short circuit of the special armature. The short-circuiting connection was done in three points, one contact for each phase.

In the same year Mr. Boucherot developed a unique squirrel-cage machine which had good starting characteristics and fairly good running characteristics. This machine had two squirrel-cage windings. One of high resistance which was placed near the surface of the armature, and another squirrel-cage winding of very low resistance which was placed below the higher-resistance squirrel-cage winding and was separated from it by a magnetic bridge. During the starting period the low-resistance winding, due to the magnetic bridge, took very little current, while the high-resistance winding, due to the location near the air gap, took practically all the current and produced good starting torque. When the machine had reached nearly normal speed, the e. m. f. due to self induction of the low-resistance winding had decreased very materially on account of the low frequency of the currents in the rotor when running near normal speed, and this decreased self-induction allowed the low-resistance squirrel-cage winding to take a very large percentage of the total current flowing in the rotor.

A few years later, in the year 1899, Mr. Zani took out a patent on a motor which had an armature with a three-phase winding. The three phases were short-circuited by a combination of three choke coils and three resistances. The choke coils being in parallel to the resistances. The three choke coils were mounted inside of the armature spider and were designed in such a manner that at standstill the iron circuit of the choke coils was closed. When the machine came up to speed, the centrifugal force pulled the iron core out of the choke coils and in this manner decreased the self-induction of the choke coils very materially. The operation of this motor is evident; at standstill, the choke coils are very effective and will hardly take any current, but force most of the rotor current through the resistances which are connected in parallel to the choke coils. When running, the choke coils lose their choking effect, due to the low frequency of the current and to the large air gaps which now exist in the choke coils. Therefore, during the running period the choke coils will take most of the current and the armature will act like a low-resistance armature.

One year later, in the year 1900, Fischer-Hinnen patented a motor which also had a single three-phase winding on the rotor. This winding was short-circuited over a set of choke coils and resistances, the resistances being in parallel to the choke coils in exactly the same manner as in a Zani motor. The only difference between the Fischer-Hinnen and the Zani motor lies in the fact that the choke coils in the Fischer-Hinnen motor have no changeable air gap. The Fischer-Hinnen motor was materially simpler in construction than the Zani motor, but for the same horse power output, required a larger frame.

It will be noticed that nearly all the motors mentioned above had some kind of a centrifugal device for connecting the rotor-starting connection into proper running connection when a speed near normal has been reached. None of these machines, however short-circuited the rotor winding in more than a few, mostly three points.

At the end of 1907 the company with which I am connected, conducted under my directions, some experiments with an armature of a repulsion-starting, induction-running motor by placing it in a polyphase stator. Between each segment of the commutator a relatively high resistance was permanently connected. These resistances gave the motor the necessary starting torque. After the machine had reached a sufficiently high speed, the centrifugal device short-circuited all segments in exactly the same manner as in a standard repulsion-starting, induction-running, single-phase motor.

The arrangement of starting resistances proved to be too bulky, but the multiple short circuit was very successful. This is, therefore, the first case in which a short circuit in a great many points was applied.

In 1908 Mr. Sparrow continued these experiments and improved the motor by short-circuiting permanently a few coils of the armature. These few coils had to carry the whole current

during starting period, and therefore, produced a heavy loss, due to the relatively high resistance of the short-circuiting turns, the armature acting as if it had a high-resistance winding. When the machine came up to speed the governor mechanism short-circuited the segments and transformed the rotor into a low-resistance rotor. A patent was granted to Mr. Sparrow in May 1911. The first motors in accordance with this construction were marketed in 1908 and a great many motors have been built since.

It was necessary to insulate the rotor windings with asbestos as the heat generated in the short-circuited coils would have been sufficient during starting period to endanger any cotton insulation. This feature gave me the idea of placing two windings in the rotor. One winding which was a straight squirrel-cage winding and one which was absolutely identical to a standard d-c. winding or a winding as used on standard single-phase, repulsion-starting, induction-running motors. In the first construction of these machines I placed the squirrel-cage winding near the surface of the rotor while the commuted winding was placed in the bottom of the slots.

In this type of machine the squirrel-cage winding takes all the current during starting period and offers high resistance.

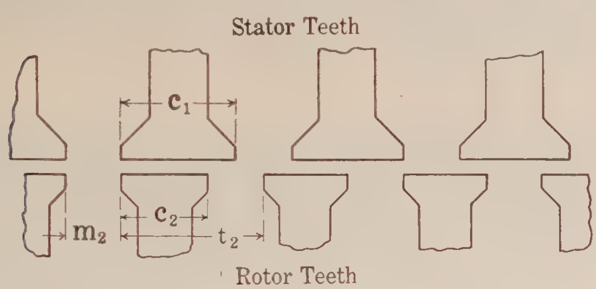


FIG. 5

In the running period the commuted winding is short-circuited and works in parallel with the squirrel-cage winding, thus transforming the rotor into a low-resistance rotor. A good mechanical arrangement of the squirrel cage is not as easily obtained with the squirrel-cage winding near the surface of the rotor as with the squirrel-cage winding in the bottom of the slots. For this reason it was suggested to me to place the squirrel cage under the commuted winding.

At first thought it seemed as if this arrangement would give an inferior starting condition and I hesitated in the beginning to adopt this construction. A more detailed investigation of the subject reveals the surprising result that the starting performance is improved by this arrangement because it decreases the rather too-heavy starting torque, but increases the rather low pull-in torque. The "pull-in torque" is the torque which the squirrel cage exerts at the speed at which the centrifugal device operates. The pull-in torque is therefore, the lowest torque which occurs during starting period. It is, therefore, advisable to have this torque raised as high as possible.

This construction with squirrel cage in bottom of the slot was adapted by us in preference to the original construction on account of the better mechanical arrangement and the better starting performance.

In this construction the squirrel cage being uninsulated and its bars being in close touch with the rotor iron it is able to dissipate very quickly the heat generated during the starting period. The heat flows from the squirrel-cage winding into the iron core and as the iron core has a great deal of mass, the temperature rise of the winding and the core, due to the heat generated in starting, will be rather small.

During the starting period it is the heat capacity of the winding more than its radiating ability which is the determining factor of the temperature rise. Later on it will be shown that with the squirrel cage in the bottom of the slot, its resistance is lower than when placed in the top of the slot and therefore, the energy dissipated during the starting period is less in the first case than in the latter case.

Shortly after this automatic starting motor with multiple short-circuiting device had been brought on the market, the public appreciated the great advantage of the automatic type of motor. As a result of this, a good many different makes are now available. Some of them are practically identical to the old Goerges motor and short-circuit the windings in only a few points. Others have three-phase resistance across three points of the armature. When the machine is nearly up to speed, these resistances are short-circuited, usually in three points.

In the design of any induction motor it is of utmost importance to determine the number of magnetic lines and the magnetizing current. Every designer has his favorite method for determining these items, and the preference must be left to the judgment of the individual.

For determining the number of lines, the writer has used for many years a method similar to the one advanced by Mr. Hamilton. The writer went, however, a step further and calculated once for all the most frequently occurring combinations. The results were tabulated and published in the *Electrical Review* and the *Western Electrician*, October, 1910. These tables refer to machines with an infinite number of slots. For a three-phase machine with sine-shaped field distribution and full-pitched winding we find from these tables a coefficient of 0.954. The e. m. f. induced in the winding of one phase of the pole is given by

$$E = 2.22 \times 0.954 \times Z \times N \times v \times f \times 10^{-8}$$
$$= 2.12 \times Z \times N \times v \times f \times 10^{-8}$$

Z = Conductors per pole per phase
N = Lines per pole
V = Frequency
f = A coefficient depending on the throw of the winding.

This formula as stated above was derived for a machine with an infinite number of slots per pole per phase. If the slots per pole per phase are only a few, a correcting factor K must be introduced. This factor, however, is in most practical cases very nearly equal to unity as will be seen from the table below:

Slots per pole per phase	K
1	1.05
2	1.015
3	1.005
4	1.002
5	1
6	1
∞	1

For commercial calculations it is usually unnecessary to consider k.

The coefficient f is unity as long as the winding spans a full pole pitch. If the winding spans α deg. which is β deg. larger or smaller than 180 deg., then $f = \sin(\alpha/2)$.

The coefficient f can, therefore, be quickly determined by a simple slide rule operation.

The writer's method for determining the magnetizing current is quite different from the method given by Mr. Hamilton, and is based on the fact that the idle volt-ampere draw of a motor equals the energy stored in the magnetic field. The mathematical expression of this physical fact is:

$$\text{Idle volt-amperes} = 2.45 \times N^{+2} \times p^2 \times 10^{-8} \times V \times \frac{\delta}{Q}$$

The idle amperes are equal to idle volt-amperes, divided by $E\sqrt{3}$ for three-phase and $E \times 2$ for two-phase, where E equals the voltage generated in the polyphase winding when the magnetic field has N lines.

P = number of poles
V = frequency
δ = single air gaps in inches
Q = effective air gaps section per machine

The value obtained in this manner represents the idle volt-amperes for the air gap only. An addition will have to be made for the idle volt-amperes necessary to drive the flux through the iron circuit.

The writer determines the effective air gap section as follows:

Let us consider one stator tooth and draw the effective crown of this tooth as function of the rotor tooth position. We obtain then a variation of the effective stator crown as given in Fig. 6. From this figure we can readily derive the average effective crown of one stator tooth as:

$$\frac{C_1 \times C_2}{A_2}$$

and this equation can be transformed into:

$$\tau_{eff} = \frac{C_1 \times C_2 \times n_1 \times n_2}{\pi \times D \times p}$$

c_1 = crown of stator tooth
c_2 = crown of rotor tooth
n_1 = No. of slots in stator
n_2 = No. of slots in rotor
D = Rotor diam. in inches
p = No. of poles
τ_{eff} = effective pole arc
Q = Eff. pole arc $\times L \times p$
L = iron length of motor

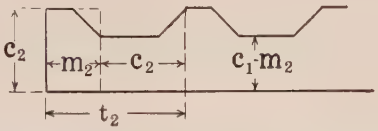


Fig. 6—Effective Stator Tooth Crown as Function of Rotor Position

The fringing can be considered by introducing for C_1 and C_2 values slightly larger than the mechanical dimensions of the crown. The well known "Carter" coefficient can be used for this purpose. For semi-closed slot motors it is usually sufficient to add to the mechanical dimensions of C_1 and C_2 the value of single air gap.

The idle volt-amperes required for the iron circuit are given by the equation $V A_i = M \times V$ where V is the volume of the core or teeth and M a coefficient depending on the magnetic induction of the circuit. M, as function of the induction, can be readily derived from a test on actual machines.

Mr. Hamilton showed in his paper some very interesting and valuable oscillograms which give the oscillations in the stator teeth of a polyphase motor. He further showed very clearly the manner in which the frequency of these oscillations is related to the number of stator teeth, rotor teeth and the speed of the machine. It might be added here that the magnitude of these oscillations depends, with all other conditions alike, on

1. Relation of slot mouth to slot pitch.
2. Skew of one of the members.
3. Rotor winding.

The influence of the rotor winding on the fluctuations in the teeth is perhaps not generally known. If the stator-teeth fluctuations are taken when the rotor has no winding, but is driven at approximately synchronous speed, then the high-frequency oscillations will have a certain magnitude.

If, on the other hand, the motor is provided with a squirrel-cage winding and the oscillogram is repeated, it will be found that the magnitude of the oscillations has increased. The writer has found values as high as four times the original value. This peculiar phenomenon is readily explained by the following:

In exactly the same manner as the rotor teeth produce fluctuations in the stator teeth, fluctuations will be set up in the rotor teeth, due to the stator teeth. If fluctuations are set up in the rotor teeth, currents must also be set up in the rotor winding. These currents will be of very high frequency and the rotor will act like a short-circuited high-frequency generator and will naturally react on its field, and therefore, produces high-frequency, fluctuations in the stator teeth which superpose themselves over the high-frequency oscillations set up in the stator teeth due to the rotor teeth when no rotor winding is in existence.

The oscillations in the stator core can be derived from the oscillations in the stator teeth if we remember that the flux in the stator core is the sum of all the fluxes passing through all the stator teeth of one pole. In performing this addition we must consider the proper phase relations of the high-frequency fluctuations in the different teeth. The addition of these high-frequency oscillations may be of such a nature that the resultant fluctuations in the core are larger or smaller than those found in the stator teeth. This reasoning immediately shows why an oscillogram taken on a search coil which surrounds the stator core is very similar, if not identical, to an oscillogram taken of the voltage produced in a search coil placed around the teeth forming one pole. In either case the search coil embraces the vectorial sum of all the high-frequency fluctuations which take place in all teeth, belonging to one pole.

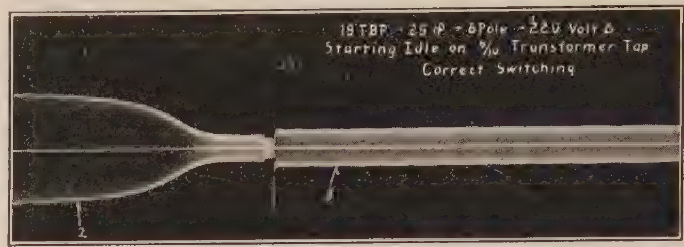


Fig. 7

Let us now return to the peculiar characteristics of the polyphase motors with automatic starting device. Figs. 7 to 15 show some oscillograms which were taken in order to demonstrate the current values which occur during starting in case of a standard squirrel-cage machine and in case of a polyphase motor with automatic starting device.

These oscillograms were taken in connection with a paper which was read before the American Institute branch in Detroit in the year 1915. One outstanding characteristic in these oscillograms is the great difference in starting current taken by a given squirrel-cage rotor depending on the time in which the switching from starting tap to running connection is made. Due to the fact that this switching is done manually, it is evident that an inexperienced operator quite frequently will switch over long before the motor has reached sufficient speed, and therefore, can draw in this manner a current from the line which is greatly in excess of a current considered safe.

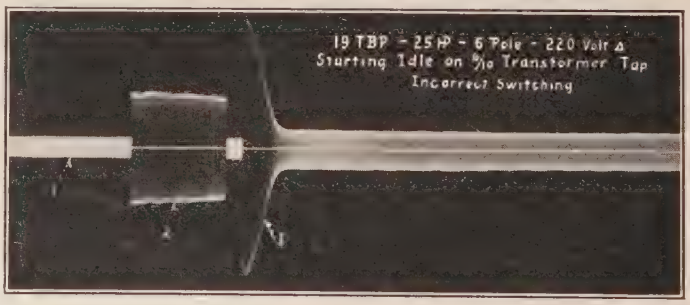


Fig. 8

Fig. 7 shows the condition of a squirrel-cage motor when starting idle with correct switching. Fig. 8 shows the same motor starting with incorrect switching. Figs. 9 and 10

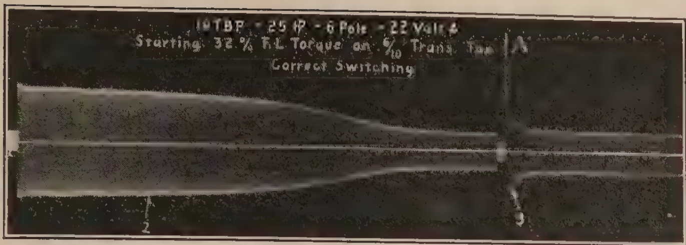


Fig. 9

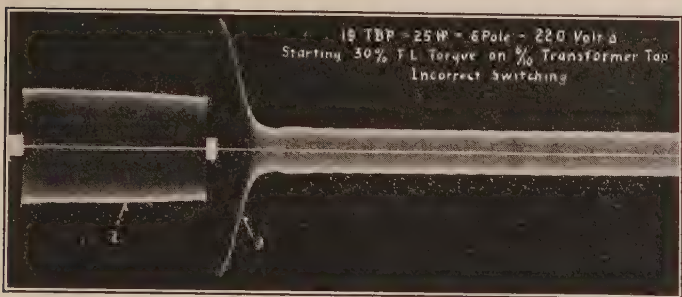


Fig. 10

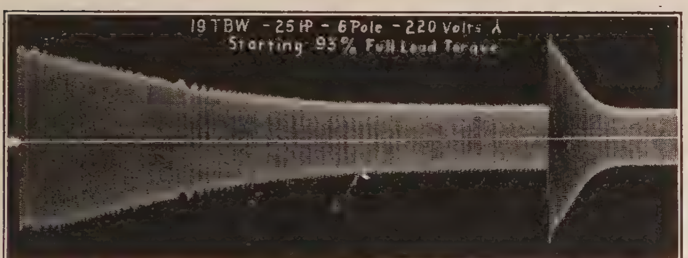


Fig. 11

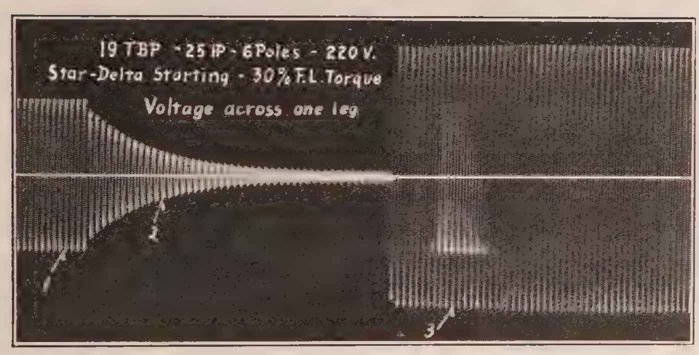


Fig. 12

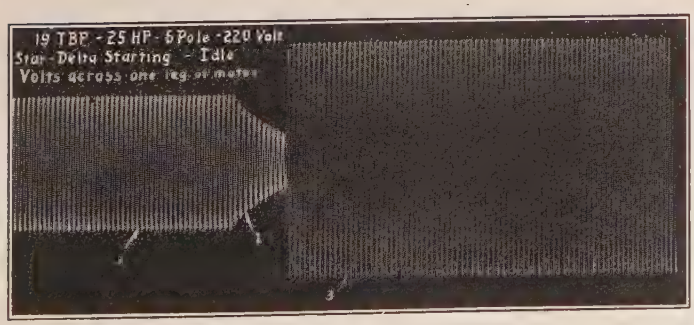


Fig. 13

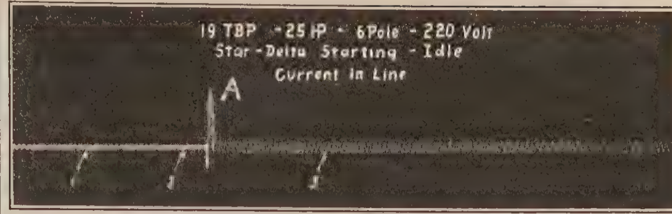


Fig. 14

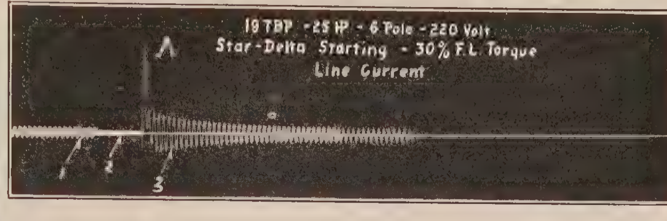


Fig. 15

show the same machine starting 32 per cent of normal torque, once when switching is done correctly and once when the switching is done incorrectly.

Fig. 11 shows the starting of a polyphase motor with automatic starting device. Naturally no oscillograms of incorrect starting could be taken, as it is impossible to start this motor incorrectly on account of its automatic feature. n the motor with automatic starting device the switching of the rotor from starting connection to running connection is always done at a predetermined speed, therefore, the current drawn during the switching operation will be the same under all conditions and is independent of the skill of the operator. These oscillograms further show a very interesting phenomenon in case the switching operations are performed on a squirrel-cage machine. When the motor has reached a given speed in the starting condition and the switch is thrown from starting connection into running connection the stator current has to die out suddenly. The rotor current, on the other hand, will not die out, but will continue to flow. Therefore, during the switching operation, the rotor currents produce a powerful field which produces in turn an e. m. f. on the stator.

Fig. 12 shows the e. m. f. across the stator terminals when rotor is running and immediately after motor is disconnected from the line. It will be seen that the e. m. f. dies out gradually. This phenomenon occurs no matter if motor is running idle or under load. See Figs. 12 and 13. When the switch is thrown over from the starting position into the running position, the line e. m. f. and the e. m. f. produced in the stator due to the rotor currents might have any phase relation in respect to each other, and therefore, sometimes these e. m. f.s will be in such a relative position as to add each other. If this latter condition occurs a very heavy current inrush will take place which naturally will result in flickering of the lamps and enormous strains in the motor.

In Figs. 7, 9, 14 and 15 these current inrushes are shown by the line *a*. This current inrush phenomenon can naturally not occur in a polyphase motor with automatic starting device because in this kind of motor all the switching is performed in the rotor circuit and not in the line circuit.

The diagrams and methods given by Mr. Hamilton are in every respect according to my judgment very useful and applicable to the average run of machines on account of their simplicity, but in applying these methods, it must always be borne in mind that in many cases certain assumptions have been made in order to get simple relations. Only by bearing these assumptions clearly in mind will it be possible for a designer to safe-guard himself against disagreeable disappointments in case of a new design of a special machine.

In motors with automatic starting devices such as described, the circle diagram as ordinarily used is not strictly true, due to the fact that the rotor has two windings which have different values of resistances and leakage reactance. Therefore, the ratio of distribution of the currents in these windings will depend to a large extent upon the speed at which the armature rotates in respect to the rotating field produced by the stator. This hint, I believe, will be sufficient to indicate why the circle diagram as usually used does not hold strictly true for this class of motors. Practically speaking, however, it is fortunate that in most cases the change in ratio of distribution is not sufficiently serious to prevent the designer from making use of this very excellent method of the circle diagram.

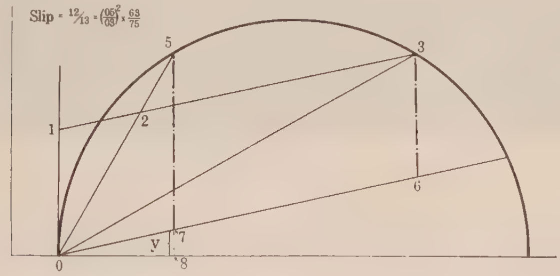


Fig. 16

The primary copper losses in a circle diagram are commonly represented by the distance of the line 0 — 6 from the horizontal. See Fig. 16. This representation is very nearly correct in all cases when current values are many times larger than normal current. For current values nearly equal to normal or less than normal the line 7 — 8 = y no longer represents the copper loss correctly. Here again a word of warning should be said. The line y represents the primary copper loss correctly only in case of motors with very small idle current. If the idle current is large, such as will occur in low-speed machines, then the line y represents a loss materially below the real stator copper loss.

Another point, which demands that the designer have clearly in mind the real laws which govern the circle diagram, is in case

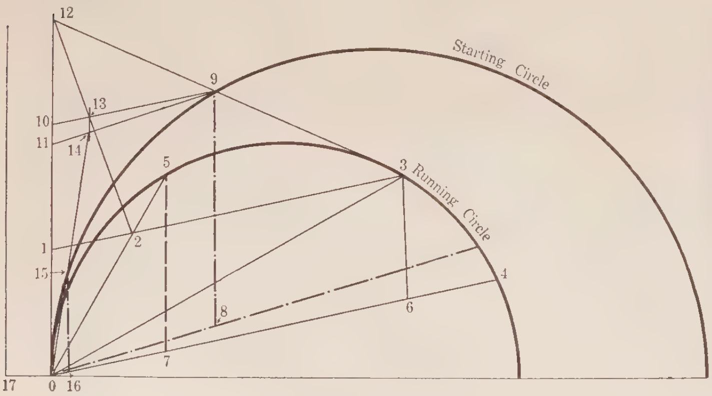


Fig. 17

of using the vector 0 — 5 in Fig. 16 as representative of the secondary current. If the stator and rotor are wound with the same number of turns, the scale for the vector 0 — 5, is strictly speaking, different from the scale used for the primary current. Fortunately, in most practical cases the difference in scale between these two vectors is rather small. But in case of machines with very large idle current the difference in scale between this rotor current and stator current may reach an appreciable value. Strictly speaking, the scale of the secondary current is equal to the scale of the primary current multiplied by the coefficient $1 + \sigma_1$, where σ_1 represents the leakage coefficient of the stator. I want to emphasize that I do not recommend in any manner that the refinements just discussed should be used in daily designing work in preference to the simplified methods, but it is necessary that the designer, when using these simplified methods, remember the assumptions which have been made in order to safeguard himself against disappointments.

In the beginning of this discussion, mention has been made of the influence which the location of the starting winding has on the starting characteristics of the motor.

In order to determine the starting conditions it is convenient to make use of a simple method for determining the slip. Fig. 16 represents a circle diagram. The lines 0 — 6 and 0 — 3 represent the stator and rotor losses respectively. In order to determine the slip for any load condition, say point 5, draw the line 1 — 3 parallel to 0 — 6 and draw 0 — 1 vertical to the base line. Connect points 0 and 5, and the ratio of line 1 — 2 to 1 — 3 represents the slip.

In an automatic-starting motor two circle diagrams exist. For instance in Fig. 17 the circle 0 — 5 — 3 — 4 represents the conditions for a fully short-circuited rotor, and that is "running conditions," and circle 0 — 15 — 9 represent the starting conditions. The line 9 — 8 represents the starting torque and distance 9 — 17 the corresponding starting current. The distance

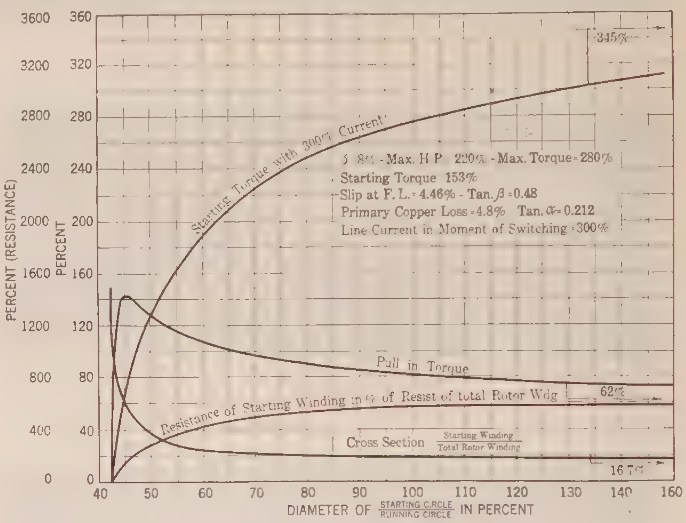


Fig. 18

of line 0 — 8 from the base line represents the primary copper loss when the motor is operating on the starting winding. For the load point 15 corresponding to torque 15 — 16 we find the slip by drawing 9 — 11 parallel to 0 — 8. The line 0 — 15 cuts 9 — 11 in point 14 and the slip is given by the ratio $\frac{11 - 14}{11 - 9}$

When the motor is running with this slip and the automatic short-circuiting device operates, the machine continues to run momentarily with the same slip but now the circle 0 — 5 — 3 — 4 must be used in order to determine the condition immediately after the rotor has been short-circuited. In order to find on the running circle 0 — 5 — 3 — 4 the point which corresponds to the slip $\frac{11 - 14}{11 - 9}$ draw line 9 — 10 parallel to the primary copper-loss line 0 — 4 and line 14 — 13 parallel to 0 — 10. Connect points 3 — 9 line. This cuts line 0 — 11 at point 12. Draw lines 12 — 13, and make 3 — 1 parallel to 0 — 4. The line 0 — 2 cuts the circle at 5 and this is the load point on the running circle in the moment of switching when the motor operates with the slip $\frac{11 - 14}{11 - 9}$, (this value is the same as

$\left.\frac{1-2}{1-3}\right)$. The line $3-6$ is the starting torque which the rotor would have if it were started with running and starting winding short-circuited.

The line $17-5$ represents the current drawn from the line immediately after the short-circuiting device has operated. It will be remembered that line $17-9$ represents the starting current. If the starting current and the "current kick" at the moment of short-circuiting the rotor are supposed to be alike, then the lines $9-17$ and $17-5$ must be made equal.

In the motor with automatic starting devices the starting currents $9-17$ and the current kick $5-17$ are usually made 300 per cent of normal current. For this assumption of starting current a series of diagrams similar to Fig. 17 has been drawn, and different values of the starting circle $0-15-9$ have been assumed but working circle $0-5-3-4$ has been held constant.

In Fig. 18 the starting torques, and the pull-in torques for different values of the starting circle $0-15-9$ have been plotted as function of diameter current of $\frac{\text{starting circle}}{\text{running circle}}$.

This diagram shows clearly that the starting torque decreases with decreasing diameter current of the starting circle, that is, with increasing leakage of the squirrel-cage starting winding. The pull-in torque on the other hand increases with increasing leakage of the starting winding up to a point near the value at which the starting torque is zero.

These curves demonstrate very clearly how a certain amount of increased leakage in the starting winding is beneficial for the starting period, because it decreases the starting torque and increases the pull-in torque.

The curves have been derived for a motor with 8 per cent leakage, a maximum h. p. of 220 per cent of normal, a maximum torque of 280 per cent of normal, and a starting current and switching current of 300 per cent. The imaginary starting torque of the motor with starting winding and running winding short-circuited was assumed to be 153 per cent.

By changing the relations of maximum h. p., torque, etc. the curves given in Fig. 18 will change their absolute values. The general characteristics of these curves remain, however, unaltered.

Fig. 18 also indicates the values which the curves for starting torque and pull-in torque approach asymptotically. It is a very simple matter to determine the asymptotes of these curves but it will lead us too far to discuss it here.

H. W. Eales: I do not know that I understand from reading Mr. Hamilton's paper, the exact relation of the circuits in this machine, but I take it that the main secondary or rotor circuit is open at the moment of starting. If that is so, I can suggest to Mr. Hamilton from my experience with similar design, that some consideration must be given to the condition of insulation in the rotor, and to the matter of keeping these contacts clean. It was my lot some ten years ago, when sent out on a trouble job, to investigate some trouble on a wound rotor induction motor in a grinding factory where motors were subject to large amounts of steel and dust. The motor in question was one of the most expensive makes of motors on the market. This particular trouble had never before been experienced, but investigation of the operating condition showed that the motor, started with the secondary open-circuited except on one phase having resistance in it. A high voltage was induced in the open circuit with the result that a breakdown occurred in the insulation. Those motors did not last more than a month and were taken out of the plant and rewound, using special insulation to overcome the high-voltage stresses; I mean high voltage with respect to the normal voltage of the rotor.

From the practical standpoint this motor will obviously lose its advantages if the automatic governor or starting switch does not function perfectly. We have the assurance of the author of the paper, that the type of governor, both of this particular make and other motors of this type, has been so well developed in the single-phase line of motors, that we need anticipate no trouble. Obviously this is a feature of the design that needs to be perfectly "fool proof." If anything happens to the starter, in an ordinary motor, as shown by various oscillograms which have been presented, it is not impossible to throw the motor on the line and after starting it the defective starter can be taken off or another substituted.

In this particular type of motor, if anything goes wrong, the motor is out of commission. It would be very interesting if the author would indicate something about the limitations of the operation of this governor with respect to voltage variations on the supply circuit, etc. I am not sufficiently familiar with complete figures on up-to-date designs of polyphase motors, but it occurred to me that the slip shown in the tables for this motor, was slightly in excess of that of other types of motors. It was noted that the full-load speed of the motor selected for the paper was 1725 rev. per min., and the slip 4.7 per cent full load. The figure that I have in mind for motors of this type, is something like 1740 rev. per min. at full load. I do not know whether this is a characteristic of the design of this type of motor, or if it just happened that way for this one particular sample.

An interesting feature in the last three oscillograms shown was the fact that the first oscillogram had a 10-h. p., single-phase, repulsion induction motor, the second was an automatic-start motor. and the third an ordinary polyphase induction motor. The scale on the screen was not given, but I take it, it was the same for the purpose of comparison. It is interesting to note that regardless of conditions with the starting current, the three motors came up to speed approximately in the same time.

One more word with regard to the governor switch which I failed to mention. As a former member of the Safety Device Committee of the Institute, I am very much interested in this governor switch. Among the points mentioned by Mr. Weichsel is that the sliding is done on the secondary circuit, and assuming variations in the power supply, momentary drops in voltage do occur. It seems to me that it may be possible to reduce materially the number of protective devices in a motor of this type. Unless there is some danger of the motor starting under load when this is not desired, there would be no need for under-voltage release coils, because if the power supply failed and then returned, the motor would come up to speed automatically. The only danger in eliminating the safety device would be the starting of a motor attached to a machine or device which might injure persons.

E. S. Pillsbury: I would like to ask Mr. Hamilton if he has tried the experiment of switching a motor of this type, from a relatively smooth voltage to a relatively rough voltage wave, to determine the change in iron loss.

A. M. Harrelson: The only thing that occurs to me that has not already been brought out this evening is the question in regard to temperature rise on the starting winding in the rotor.

I would like to have Mr. Hamilton touch upon any information he may have as to what the temperature rise is in the rotor winding and how often the motor can be started without causing trouble.

I agree with Mr. Hamilton that the starting winding in the top of the slots gives better starting characteristics, as is clearly shown in the circle diagrams showing comparative conditions with starting winding in top and in bottom of slots. The winding in the top of slots has the advantage of being cooled by the air as the motor comes to speed.

A. H. Timmerman: There is little to add to the discussion except to point out the fact that a motor of this type does not cause the disturbance in the line made by the ordinary squirrel-cage motor. In his discussion Mr. Weichsel, in describing his oscillograms, taken a number of years ago while carefully studying this subject, showed that the squirrel-cage type of motor when started by a compensator incorrectly operated, may cause

a disturbance equivalent to twenty or thirty times normal full-load current. With the type of motor discussed in Mr. Hamilton's paper, no such condition can be obtained, because as Mr. Weichsel pointed out, the switching operation which consists of short-circuiting one of the armature windings, does not open or change the primary circuit connections.

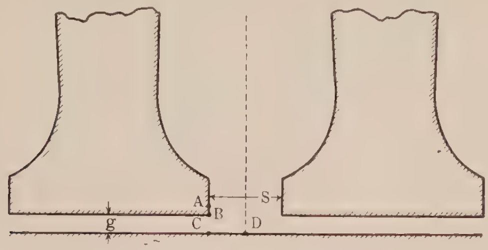


Fig. 19

W. L. Upson: In considering all these losses, added losses and so on, I notice that the friction and windage losses are pretty nearly 50 per cent of the total. It seems as though in the paper and in the discussion, the windage losses were taken more or less for granted. We permit so much windage loss in order to get greater capacity. Would it not be feasible or practical to discuss in this paper the cutting off some of the windage loss when extra ventilation is not needed, that is to say, when the motor is not carrying much load? This might be accomplished by the use of a device somewhat similar to the switch used in changing from starting to running position, which should operate at three-quarters load. Would this not considerably improve the efficiency at light loads?

A very striking point brought out by the speaker was the difference in the operating characteristics with the starting winding outside and the starting winding inside of the running winding. It seems to me that, in the design of a motor of this kind, this brings out the desirability of giving a great amount of attention to minute details relating to the arrangement of windings, size of slots, and the design of teeth.

It has been mentioned that motors of this type do not produce as great fluctuations on the line as ordinary squirrel-cage motors do. Is it possible that, due to this fact, these motors can be safely designed for higher flux densities than can be safely used with squirrel-cage motors?

J. L. Hamilton: The method of getting the winding constant as outlined by Prof. Lanier, is interesting and one that is used considerably, and as is shown, agrees with the second method employed by the author. It is therefore apparent that there are several methods of getting the winding constant, which give the same or approximately the same value, and one may therefore select the method which is considered the most easily applied. The information given in reference to the fringing of the flux at tooth tips, is well brought out.

In order that we may have this subject properly covered for the motor which was analyzed in the paper, the following information is given:

In an article by F. W. Carter, in the *Electrical World & Engineer*, of Nov. 30, 1901, a method is shown for calculating the effect of the fringe at tooth tips, and a curve is drawn from the calculations covering a wide range of design constants, that is, slot opening to air gap.

Fig. 19 illustrates a field or armature tooth with the opposite member solid or not slotted. Fig. 20 gives curves showing the effect of the fringe. Curve 1 is the same as was shown by Carter. We have found that this curve may be calculated by a much shorter method than was given by Carter, as follows:

One member, say the rotor, is assumed to be solid, that is, it has no slots, and the other member, say the stator, is slotted as illustrated in Fig. 19.

The flux emanates uniformly throughout the crown of the tooth of the stator. The fringe flux is assumed to enter the rotor uniformly over the distance $C\ D$, and to emanate from the stator tooth uniformly over the distance $A\ B$. The distance $A\ B$ is of such a length as to give approximately 130,000 lines per square inch, for the fringe flux, all of which is assumed to emanate from the side of the tooth over this distance.

The length of $B\ A$ is divided into equal parts as is also the length of $C\ D$, and lines are drawn connecting these points. The reluctance is obviously proportional to the length of these various lines, which is easily calculated.

By summing up these fringe lines in these zones, the total fringe is obtained. This integrated value divided by the flux which would enter the armature if the tooth were above the lines $C\ D$, gives the percentage of one half of slot opening or distance $C\ D$ which is to be added to that side of tooth crown. As the same amount is to be added to the other side of the tooth crown, the above percentage is therefore the correct function of the slot opening S, to be added to the tooth crown to get the effective tooth crown. By making these calculations for a number of slot openings S, and air gaps G, the curve 1 Fig. 20 is obtained, which coincides with the curve as given by Carter. The reason for using the length $B\ A$ which gives the density of 130,000 lines, is that even with 130,000 lines density in commercial electric sheets, the permeability is still about six times that of air. It is therefore reasonable to suppose that no appreciable leakage will result over a wider, if indeed as wide area.

Curve 2 Fig. 20, likewise, gives the function of slot opening S to be added to the tooth crown, if we assume all of the tooth flux emanating from the point B of the tooth. It is probably true that this curve gives results more nearly in line with the actual conditions, than does curve 1, as it is evident that the fringe flux will emanate from a small area at the point B, until a density of considerably above 130,000 lines per square inch results.

It is evident, as the curves indicate, that as the distances $B\ D$ and $A\ D$ approach each other; and therefore the functions f of slot openings approach each other; that the slot opening S becomes very wide as compared to the air gap g, which conditions obtain in wide open slots.

As mentioned above, curve 2, Fig. 20, gives the constant for leakage flux, assuming one member without slots. Prof. Lanier has pointed out that when the rotor is also slotted, the leakage

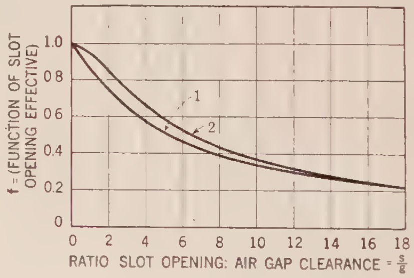


Fig. 20

constant F, is obtained precisely as from the curves Fig. 20, assuming the stator without slot openings.

If, however, the stator and rotor have a different number of slots as is usually the case, the correct constant f, or function of stator slot opening, may be obtained from the product of the stator constant times the rotor constant, times the ratio of the total number of stator slots to the total number of rotor slots.

In the paper, an arbitrary fringe factor of 0.375 was used as experience has shown that for the class of motor under discussion, this value gives consistant results.

In order that a quantitative idea may be gained as to the effect of different values of function f, the magnetizing current calculation of the paper was figured by using the constant function

f as obtained from curve 1, Fig. 20, which gave a calculated magnetizing current of 5.87, compared to 5.64, the observed magnetizing current, or 4 per cent greater. Likewise, the function f from curve 2 Fig. 20, gives a calculated magnetizing current of 5.78 as compared with observed magnetizing current of 5.64, or 2 per cent higher. It is well to bear in mind in considering these refinements, that they are not generally justified, as for instance, we have assumed in calculating the magnetic flux in the paper the applied voltage to the motor is the counter e. m. f. of the motor. The counter e. m. f. being slightly less, will give a calculated magnetizing current slightly smaller than the above figure indicates, and more nearly in conformity with the observed current, 5.64.

It is well in this connection, to point out that utmost care should be exercised to get the correct theoretical understanding of the various factors in the design, but it is useless to make too many refinements in the calculations, such as the slight difference in function of slot opening to be used, as it is not practical to know the exact dimensions of the tooth and tips to the degree which would warrant such close approximation. For instance, in smoothing the slot opening S for receiving the wire, the point B may be removed to such an extent as to result in a much larger variable.

I agree with Prof. Lanier that in getting the magnetizing ampere turns for the tooth, that the density at one third the tooth length from the minimum section be considered as the average tooth density, will give satisfactory commercial results where the maximum density of tooth does not exceed 110,000 lines per square inch.

Prof. Lanier has given seven sources of added iron loss. It would be very interesting indeed to know the relative importance of each of these component losses. It is the writer's impression that item 5, or tooth pulsation losses, (hysteretic and eddy current losses in the tooth, due to the high-frequency flux ripples) is by far the most important of the enumerated sources of loss for motors such as the one under discussion.

The historical sketch given in Mr. Weichsel's discussion, adds materially to the value of the paper.

The rotor construction with the squirrel-cage winding in the bottom of the slot, is not necessarily better, nor is better starting performance obtained. The winding in the bottom of the slots, readily gives up its heat during the starting period, to the rotor core, it is true, but it is also true that the winding in the top of the slots also does likewise. There is the advantage of better ventilation with the winding in the top of the slot.

Fig. 21, shows comparative starting characteristics of the size and kind of motor analyzed in the paper, with starting winding in the top of slot and starting winding in bottom of slot, taking the same static current. These curves are the result of careful tests made with the two rotors. The performance after the governor acted, was so nearly alike for the two rotors, that one set of curves accurately represents the performance between the speed at which the governor acts and synchronous speed. It will be noted from a comparison of the curves for the two rotors, that the pull-in torque and the static current are the same.

The static torque and the starting torque, until approximately the correct speed for governor action is reached, are materially higher for the rotor with the starting winding in the top of the slots. Likewise the power factor is materially higher throughout the starting period for the winding in top of slot.

The resistance of the winding in the bottom of the slot, is lower than that of the winding in the top of the slot, to give the same static current and pull-in torque, due of course, to the increase in leakage reactance of this winding. However, even though the winding in the top of the slot, takes more energy at a given instant, it also develops greater torque in the same proportion and therefore accelerates the load in a shorter time, hence does not necessarily mean greater heating during the starting period, but may in fact result in less.

The power factor curves Fig. 21 show that with starting winding in the top of the slot, the motor has a power factor throughout its starting and operating range, of not less than 80 per cent. This characteristic is of great importance to central stations in obtaining good voltage regulation on feeders, circuits, and generator capacities with ever increasing loads.

The comparative results indicated by Fig. 21 have been found to obtain in the various sizes of automatic-start polyphase induction motors.

In general we may say, that rotors with starting winding either in the top or bottom of the slot, are entirely satisfactory in this type of motor and may be used with entire satisfaction.

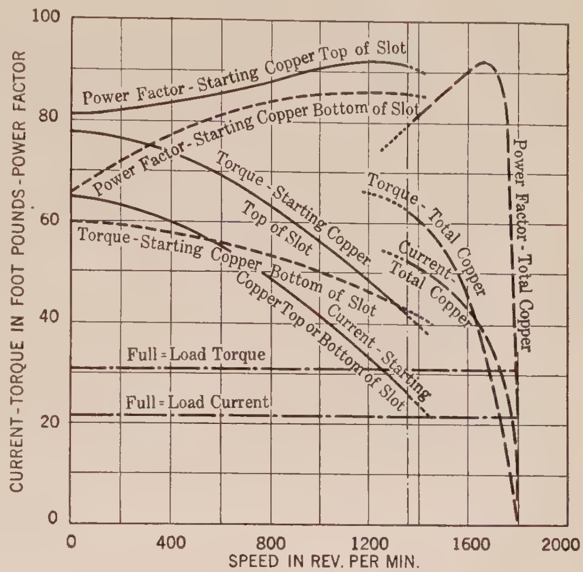


Fig. 21

Mr. Weichsel has stated that the ripples in the stator yoke are a summary of the flux ripples in the stator teeth. He also states that this may result in a flux ripple in the yoke, of a greater or less value than in the individual tooth.

We believe both theoretical calculations and observations show that the yoke ripples are always of smaller amplitude than the tooth ripples. For instance the discussion of this point in the paper and oscillograms B and f, also — and L, show two different voltage waves applied, one being smooth and the other rough, and the ripples in percentage of fundamental wave are very much smaller in the yoke than in the teeth in both cases.

Mr. Weichsel's oscillograms on starting of squirrel-cage motors with compensators, correctly and incorrectly, and oscillograms of starting the automatic-start polyphase motor which cannot be started incorrectly, are very interesting and instructive.

His oscillograms, Figs. 8 and 10, show a rush of current when the compensator is thrown from starting to running position, of about 700 per cent of full-load current. This is not only what may happen, but what does very often happen unless considerable care is taken in starting squirrel-cage motors with a compensator. Not only does the squirrel-cage motor and its compensator take as much or more current when started properly than does the automatic-start motor, which cannot be started improperly; but the squirrel-cage motor has a very low power factor during the starting period, and in addition has a low starting torque, appreciably less than full-load torque, if the static current and rush of current, when the compensator is thrown from starting to running position, is held to 350 per cent of full-load current.

Mr. Weichsel has also clearly shown how the large surge of current may occur and in practise is found to occur frequently when starting squirrel-cage motors with a compensator. He also points out clearly that the automatic-start polyphase motor

has switching of current in the rotor, therefore the opportunity for surge of line current is eliminated.

Mr. Eales' question as to whether in this type of motor, the rotor insulation has to withstand considerable temperature, and also Mr. Harrelson's question as to the frequency with which the motor can be started without injuring the rotor insulation, may be answered together.

A motor of the specifications analyzed in the paper, was tested as follows:

The motor was started with full load of large inertia, and operated at full load for a period of three minutes (minus nine seconds, the time necessary for the motor to come to rest), then started again. In other words, this motor started and operated at full load and started again on a cycle of three minute duration, until the motor rose to a constant temperature. It was found that the rotor had a maximum temperature rise of less than 45 deg. cent. There is probably no commercial requirements even approximating the severity of this test. As it is not possible for a voltage as high even as 50 volts, to occur at any point of the rotor winding, it is obvious that no breakdown in rotor can occur as long as the rotor insulation is at all intact. Heat-resisting insulation is used between the starting winding and the insulated winding connected to a short-circuiting device, to take care of an extreme condition where a motor is subjected to a starting load, far in excess of the full-load capacity of the motor.

Mr. Eales has asked whether complete protection to this type of motor can be expected with fuse or thermal cutouts only. This type of motor should be amply protected with thermal cut-out of proper size for the motor. except for conditions where the motor attempts to start or operate for a considerable period on a voltage appreciably below normal. Obviously under this condition, the motor could not come up to full speed; and due to the greater heating of a motor operating on starting winding, and also due to the low speed at which the motor would operate and the poor ventilation which would be obtained, it would be possible for the rotor to overheat. Where low voltage is likely to be applied to the motor, a low-voltage protective device is advisable and in all installations, desirable.

In regard to Mr. Eales' question as to the slip of the automatic start motor as compared to the squirrel-cage motor, there is no reason whatever why the slip of the automatic-start motor should be any greater than the commercial squirrel-cage motor. In fact the slip should be less for the automatic-start motor than for commercial induction motors with compensator, having suitable starting characteristics.

Answering Mr. Pillsbury, we have tried the experiment of switching a motor of the kind described in the paper, while running idle, from a relatively smooth voltage wave to one of relatively rough voltage wave, and found that a very slight increase of wattage was observed, of possibly two or three per cent of the total iron loss in the motor. We may therefore conclude that relatively rough voltage waves in general, have a small effect on the iron loss of the motor, as was also concluded from a study of oscillograms shown in the paper.

As has been pointed out by Mr. Timmerman, this type of motor does not cause as much line disturbance as is caused by the squirrel-cage motor with compensator. His remarks as to the reliability of this type of motor are also of interest and value.

In regard to Prof. Upson's remarks as to the possible saving of power and therefore increasing efficiency due to reduction of windage, I will say that of 250 watts friction and windage loss in the motor under discussion, not more than 10 or 15 per cent is due to air friction. Therefore, a very slight change in efficiency would result if this loss were entirely eliminated. We have only to bear in mind that the usual 16 in. desk fan consumes 80 watts and has less than 50 per cent efficiency, so less then 40 watts are used in actually driving this fan moving about 1500 cu. ft. of air per minute. As this amount of air is far in excess of that required for a 10-h. p. motor, a comparative idea is gained of the splendid ventilation which may be had for a small expenditure of power.

We do not believe that polyphase automatic-start induction motors should be worked at higher flux densities than are used in the squirrel-cage motors, because the same general laws of design of the magnetic circuit apply in both cases.

Failure of Center Shots in Blasting*

In large-scale blasting, it is customary to fire many shots simultaneously. The electric detonators are usually connected in series, and are fired either from a power circuit or from a blasting machine with large capacity, operated by hand.

When firing with a blasting machine, trouble with missed shots has been frequently experienced. Under these circumstances, the shots that fail to fire are often a group in the center of the series. Various explanations have been given as to the cause of the failures. The electrical section of the Bureau of Mines, has been making interesting tests to discover the causes of misfire.

Whatever the source of the firing current generator, magneto, or battery the current delivered through a shot-firing circuit is determined by the total resistance of the circuit; and all current leaving the positive terminal must return to the negative terminal. If a metallic circuit is well insulated, practically all of the current keeps within the circuit; but in a shot-firing circuit, where the wires are often in contact with the earth as in wet holes, and where the insulation of the leg wires is inadequate to prevent leakage, the current may take various paths through the wet earth.

Conclusions

The results of these tests showed that if a large number of the common electric detonators are connected in series and fired under wet earth conditions, a large leakage of firing current occurs, and the detonators at each end of the series circuit may fire while the middle ones misfire. The detonators near the positive end will fire because not enough leakage has occurred to cause a misfire; those near the negative end will fire because enough current has returned to the circuit.

The reason why the middle detonators misfire is not necessarily because the current through them is too small to fire an electric detonator, but because it is not sufficient to fire them before the firing of the end detonators has opened the circuit. It has been found in practise, using hand-operated machines, that such misfires are more dependent on the current gradient in the circuit than upon the minimum value of current, and that it does not help much to increase the firing current to the amount given by a larger hand-operated machine.

Recommendations

As a means toward the elimination of the misfiring of center shots, it is recommended that the following practises be used whenever shots are to be fired in wet holes:

1. Use water-proofed electric detonators with enameled leg wires.

When making connections with enameled leg wires, care must be taken to scrape the ends of the wires well, otherwise the enamel will prevent good electrical contract.

2. Fire the shots from an ungrounded power circuit that has a capacity of at least 30 kw.

3. Use extra care when tamping the holes in order not to damage the insulation of the leg wires.

4. Arrange the connections between the detonators so that they are supported clear of the earth or any other conducting medium.

*Extracts from Report of Investigations, Bureau of Mines, Department of the Interior. By . LC. Ilsley and A. B. Hooker.

A Million-Volt Testing Set

BY A. B. HENDRICKS, JR.

Associate, A. I. E. E.
Transformer Engineering Dept., General Electric Co., Pittsfield, Mass.

Story of the Million-Volt Testing Set.*—The item of the greatest moment in this work is the fact that for the first time in the history of the world the extremely high power potential of a million and a half volts (over 2,000,000 volts peak value) was reached and an electric spark discharge was repeatedly caused to take place between sharp electrodes spaced fourteen feet apart. No damage was done to the equipment. This marks a remarkable accomplishment.*

A pertinent question is—what of it? The modern physicist and chemist who are trying to realize the ancient alchemist's dream of transforming one element into another may be able to approach one step nearer realization by the availability of this new intensity in high potentials. In this high potential is available a new means of speeding up the tiny disrupting projectiles, the electrons, which blast the elements into fragments. These fragments are actually other elements of lower atomic weight. The art of X-ray production may also be benefited. These factors which deal with the ultimate nature and characteristics of matter are less in the mind of the developmental engineer than certain practical results immediately realizable.

Three transformers are ready to produce three-phase currents for a possible transmission at a million volts. The engineers of the two big California transmission systems are just reaching the new high mark in practical transmission of power at 220,000 volts. While no projects at a million volts are being contemplated at present, who can say with the ever-advancing accelerations in progress how soon such a step may become advisable. At any rate with the equipment available there will be found an answer to the question—If not, why not?

The new million-volt, three-phase installation will be valuable in magnifying the possible troubles which may arise in the 220,000-volt practical installation—that is to say, such troubles as may arise from the electric pressures now being pushed above the known field of operation. Information thus collected can be turned immediately to the advancement and economics of the applied art.

Also the testing set will have its uses in the near future for various researches in insulation, ionization, spark discharges, lightning, high frequencies, designs of apparatus, and so on.

A million and a half volts is not by any means the upper limit of high electric pressure immediately attainable. The author in producing this pressure attained a million volts effective from one line to ground and, therefore, by simply duplicating this set two million volts effective (2,800,000 volts peak value) will be available, all in due time.

A million and a half volts produces a discharge of the same general appearance as at lower voltages at 60 cycles. The illustration, Fig. 22 shows all the typical effects, namely (a) the corona or brush discharge at the high tension terminal which precedes the spark discharge; (b) the initial spark discharge at full voltage, through the air; the spark manifests itself in the photograph as a brilliant white streak; and (c) the successive arc discharges at low voltage in places where air currents are strong are pictured in the photograph as lace work. Each successive peak of dynamic current at 60 cycles finds a new path and the space between these threads of light does not show because the current is low and the intensity of the arc insufficient to affect the photographic plate. Incidentally the brush discharge is much stronger in the next illustration, Fig. 23. More time was given to record it on the photograph.

Odd Spark Discharges. *In one test at a million volts effective value, (or 1.4 million volts at the peak of the generator wave) from the transformer terminal to ground and a spark gap of nine feet, the discharge preferred to find a new path 18 feet long (2.7 million volts instantaneous value of potential). The exact nature of this phenomenon is obscure. It is evidently associated with high frequency. It is just as surprising in its occurence as it would be to drop a heavy weight nine feet above earth and observe it move off in a path 18 feet long before reaching the earth. No photographs of this discharge are shown.*

Another accidental discharge took place from the cap of the main terminal to an iron fence in the background, Fig. 19. The points are marked "A" and "a" and the arc is shown nearly end-on in Fig. 18.

While the designs of these transformers are familiar to the transformer designer with certain elements amplified to meet the conditions of higher voltages, there are nevertheless unique features. One of these features is the use of 30 miles of paper-covered aluminum strip, instead of copper, in the high tension winding of each of the 500 kv-a. transformers. This aluminum strip was chosen not only to give desirable mechanical strength to withstand the frequent short-circuit strains to which a testing transformer is subjected, but also to give a better distribution of the internal static strains. The relatively large dimensions of the aluminum strip give the high voltage winding about ten times the kilovolt-ampere capacity of the low voltage winding. Incidentally the mechanical and electrostatic requirements make it impractical to build a small transformer for these high potentials.

Another unique feature results from the combination of very high voltage and the above mentioned strip winding. It is a familiar fact that the exciting current of the usual transformer lags behind the impressed wave of electric pressure. In these test transformers it does not. The exciting current is actually in advance of the wave of impressed pressure. The high voltage windings act on the current as would the capacitance of idle transmission wires.

The High Voltage Bushing and Terminal. *Three notable features are the large metal cap, the large insulating tube and the heavy aluminum sleeve which supports the bushing on the cover of the iron case of the transformer. The data are given in Fig. 12.*

Without reviewing the specialists' details of this new work, it is of interest to stand off from the technical side and take a glance at the nature of the accomplishment without details. The favorite method of using analogies will be resorted to.

The Analogy of a Bridge to a Transformer Design. *Bring to mind the spanning of any river by a bridge made up of numerous strips of steel in triangular connection at their ends. No single strip has to withstand the total weight passing over the bridge. The stresses are distributed among the steel members. Likewise in a transformer there is a distribution of insulation along the thirty miles length of wire in the coils. At no spot does this insulation have to withstand the entire electric pressure of a million volts. Like the mechanical pressure in the struts of the bridge, the electric pressure is distributed all along the insulation.*

So much for likenesses. Now for the contrast of differences. If the bridge were jacked up at both ends until it reached an elevation equal to its length and then released to fall by gravity, not much of the bridge would be left after it struck its piers. The similar and unfortunate accident to the Quebec bridge during its construction had its well-known destructive effects. Momentarily the end struts were called on to support the entire load. They could not do it. On the other hand, a transformer has to be designed to withstand this sort of treatment. Just before a spark takes place across the gap of fourteen feet, there is a peak pressure at the top of the sine wave of over two million volts. When the arc suddenly forms, the voltage across the gap immediately drops from 2,000,000 volts to about 200 volts. The interesting point in this analogy is that the 2,000,000 volts pressure is shifted to the end turns of the transformer. There is no longer an even distribution along the insulation, but, unlike the bridge, which in practise is not called on to stand a fall, the trans-

former coils must be so designed as to distribute and withstand this suddenly imposed local stress. It is apropos in this respect to point to the choke coils on the top of the bushings in Fig. 19 as the external device to take this first shock of the tumble from 2,000,000 volts. The rest of the effect must be obtained in the internal arrangements, in an uneven distribution of insulation in the coils and in a relatively even distribution of the static stresses by means of several forms of static shields.

How to Interpret the Photographs of Electric Discharges. Comments in General. *To interpret a photograph involves an analysis of the several factors which produce a trace on the photographic plate. In their historical order in a test these factors are: brush discharge, spark discharge, arc discharge and and duration of discharge.*

1. The brush discharge of corona (if the potential is sufficiently high to produce it.) Brush discharge is not very strong actinically as compared to spark and arc discharge, so the exposure of the photographic plate must be longer to produce a picture. If the voltage is held some time just below spark voltage this brush discharge radiating a few inches from the electrodes will be superimposed strongly on the spark and arc traces. A good example is given in Fig. 23 on the high-tension electrode at the left at one million volts above ground potential. The brush discharge is less marked on the right electrode which is at one-half million volts from ground potential The brush discharge is also less marked in all the other photographs of discharges.

2. The spark discharge. When the electric strength of the air is exceeded the oxygen and nitrogen of the air suddenly become conducting in a brilliant streak. The voltage of the spark is full value produced by the transformer and, furthermore, at the peak value of the potential wave. Even if the current is limited by resistance its initial value is higher than by subsequent value, due to this high voltage. The voltage and the current both being at maximum the temperature of the spark is at a maximum and its actinic action on the photograph is most intense. Two separate well-marked streaks of spark discharge are shown in Fig. 22.

3. The arc discharge. As the spark, by its rising temperature, becomes a better conductor, metal vapors from the electrodes are fed into it by the current and the voltage between electrodes drops from two million to perhaps two hundred volts along the arc thus formed. The natural inductance of the transformer windings and the artificial series resistance limits the current in the arc. As compared to peak values of current, the arc is so nearly extinguished between alternations of the generator that the relatively weak light produces no effect on the photographic plate. Incidentally there are always relative effects which can be shown by an adjustment of the aperture of the camera. Consequently, as air currents carry the arc from one position to another a faint streak on the photograph will be produced at each peak of the generator wave of current. Under movements of the arc favorable to photographing a lace-like trace will be found. Such a lace-like record will be found distinctly in Fig. 22 and also on several other photographs of arcs. In Fig. 22 nine and eleven distinct alternations can be counted in each of the two separate discharges.

A note should be made that if the arc is actually extinguished by cool air currents in any part of its length, the electric pressure will rise across the gap made by the cool air currents and a more or less intense spark will be formed in reestablishing the arc. So in a lacework of arc traces some threads of light show occasionally more intense than the average trace.

Also where each successive alternation of arc falls on the same point on the photograph the trace naturally becomes more marked. These super-imposed traces are evident in a number of places through out the fourteen feet of arc length in Fig. 22.

4. Duration of the arc. After taking account of the brush discharge, the spark discharge, and the arc discharge, the fourth factor is either the duration (measured in the number of alternations) of a single arc, or the number of successive arcs exposed on one photographic plate. The arcs of Fig. 18 and 20 are good illustrations of several superimposed discharges of long duration. The successive arcs become an inseparable conglomeration.

With the foregoing elements of the art of photographing electric discharges in mind it is possible to give the proper significance to all the phenomena in the pictures. More illustrations of electric discharges at over a million volts will be given in the next number of the Journal.

THE highest voltage now used in power transmission is 220,000 volts between lines three-phase, or 127,000 volts to neutral which is grounded without resistance.

This transmission potential seems a long way below a million volts and the usefulness of the latter is not at once apparent. However, the circuit breakers of a 220,000-volt system are required to be tested at 500,000 volts, and the bushings are designed for a dry arcover of not less than three times the line voltage, or 660,000 volts. Tests on line insulators and lightning arresters may be at equally high potentials.

The requirements for ordinary commercial tests thus approach 700,000 volts to ground with the tendency constantly upward and, furthermore, in the potential employed, experimental and research work are also always far beyond commercial practise.

In X-ray work, especially for therapeutical purposes as in the treatment of cancer, the penetration of the rays is inversely as the wave length or proportional to the maximum frequency, which in turn varies directly as the voltage.

X-ray tubes are seldom operated at potentials (d-c.) of over 100,000 volts which corresponds to an X-ray frequency of 24,000,000,000,000,000,000 or 24×10^{18}. This frequency looks formidable but it is far below the frequency of the gamma rays of radium which are therefore preferred for cancer treatment in spite of the great cost of radium. A potential of something like 2,000,000 volts would be required for an X-ray frequency equal to that of the gamma rays (about 48×10^{19}).

There is evidence to show that atoms may be disintegrated by high-voltage discharges of great intensity, which therefore makes the high voltage useful in physical research. Thus the engineer, the physician, and the physicist are alike in aiming at infinity in their demands for ever higher potentials.

The million-volt testing set here described is a step forward in this direction. It was designed and built for the high voltage engineering laboratory of the Pittsfield Works of the General Electric Company.

The set was primarily designed for several connections, for example; (a) a million volts, three-phase, with neutral grounded; and (b) a million volts, single-phase, with either one end or the neutral grounded. The transformer may be connected and used in other ways.

It is the potential above ground that is of chief importance so far as size, cost and difficulty of design and construction are concerned. The total difference of potential in any source of high voltage above ground may ordinarily be doubled simply by duplication of the apparatus. Thus, 2,000,000 volts with neutral grounded might be obtained without difficulty by adding one unit with its exciting transformer to the present set. The same considerations hold good generally—it is the voltage above ground, that is, to the neutral point, that involves the difficulties.

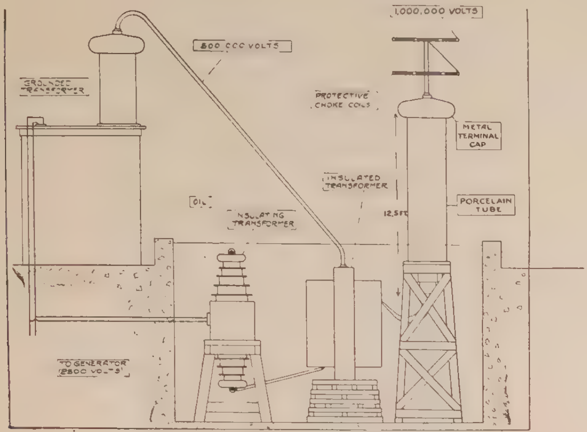


FIG. 1—MILLION-VOLT TESTING SET

Showing the general arrangement of the two main transformers, the insulating transformer, and the high tension bushing standing on a wooden support in a large tank of oil.

The complete equipment comprises three main transformer units of 578,000 volts each, also when two units are connected in series for a million volts to ground there is an insulating exciting transformer and a million-volt terminal. The general arrangement in this case is shown in Fig. 1, and the scheme of connections in Fig. 2.

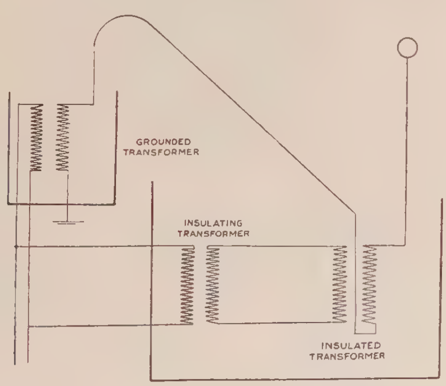


FIG. 2—MILLION-VOLT TESTING SET

Showing a simplified scheme of connections of the apparatus given in Fig. 1.

To obtain a million volts to ground the insulating transformer, line transformer, and million-volt terminal are placed on insulating stands in a large open oil vat which was already available. The line transformer is stripped of cover, terminal and other unnecessary parts and the transformer proper, only, is placed in the large tank under oil.

Main Transformers. There are three main units which are identical and each is complete in itself. Several views of this transformer unit are shown in Figs. 3, 4, 5 and 6. The normal rating of each is 60 cycle, 500 kv-a., 578,000 to 2500 volts.

One terminal is brought out through a high-voltage bushing. The other terminal is connected to a film cutout on a terminal board on the cover, and dead grounded. An ammeter and wattmeter may safely be connected directly in the high voltage circuit at this point since it is at ground potential.

A voltmeter coil encircles the high voltage coil stack at the bottom or grounded end and, having a ratio of 1000 or 2000 to 1 with the high voltage winding, reads directly in kilovolts or half kilovolts. This coil also supplies the shunt circuit of the wattmeter and is grounded.

The odd voltage of 578,000 was chosen to give exactly 1,000,000 volts, three-phase.

The low-tension terminal boards are shown in Fig. 7, low voltage in the middle, film cutout at left, voltmeter coil terminal at right.

Insulating Exciting Transformer. (See Fig. 1) This is used to excite the line unit when two main units are used in series for 1,000,000 volts to ground. The rating is 60 cycles, 500-kv-a., 2500 to 2500 volts.

The secondary is insulated for 500,000 volts working stress between primary and secondary, the whole transformer without a tank being immersed in oil in the large open vat, to be described later.

Million-Volt Terminal. (Fig. 12). This is supported on an insulating stand, Fig. 1, at one end of the large open vat, the so-called "ground sleeve" being under oil and 500,000 volts above ground. The central conductor, cap and two protective choke coils are 1,000,000 volts above ground. Except in length this terminal is almost identical with those used on the main units for 578,000 volts (Fig. 13).

Two spiral choke coils of bare aluminum wire with parallel high resistances are used on all terminals, although not shown on the grounded unit in Fig. 1.

Generator. The sine-wave motor-generator set consists of a compound-wound, interpole, continuous-current motor rated 550 volts, 625 h. p., 900 rev., and is direct coupled to two sine-wave, single-phase, 60-cycle generators rated 2300 volts, 500 kv-a. each.

The generators were especially designed for good wave form, the revolving field being of the round rotor type and wound like a direct-current armature, some of the coils being short-circuited to balance armature reaction. The two generators permit the use of two independent testing sets at the same time, one for 578,000 volts and one for 1,000,000.

Voltage control is entirely by generator field excitation and series parallel armature connections.

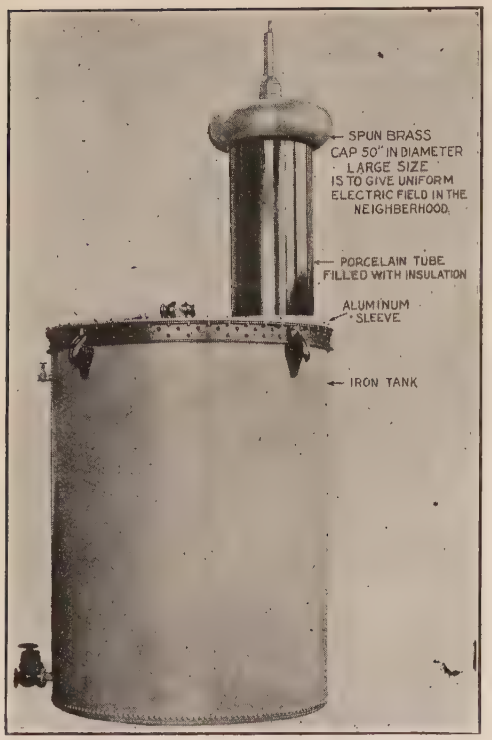


FIG. 3—EXTERIOR VIEW OF HIGH-VOLTAGE TESTING TRANSFORMER

Rated at 60 cycles, 500 kv-a., 2500 volts to 578,000 volts

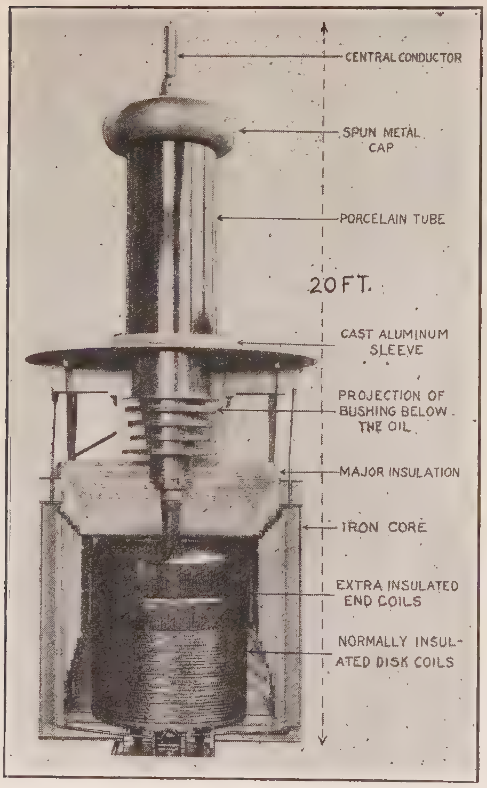


FIG. 4—HIGH-VOLTAGE TESTING TRANSFORMER REMOVED FROM THE TANK

The rating is 60 cycles, 600 kv-a., 2500 volts to 578,000 volts.

DETAILED DESCRIPTION

Main Transformer. 578,000 *Volts,* 500 *Kw.* (*Fig.* 3) The design is of the same type as that used for the past ten years for all sizes of testing transformers built by the General Electric Company, and in many respects resembles its standard power transformers, especially in sturdiness of construction and the use of the same type of core, coils and insulation.

Fig. 4 shows the transformer removed from the tank, and may be compared with Fig. 8 showing a 5-kw., 50,000-volt testing transformer. The total height to top of each terminal is 20 ft. and 3⅓ ft. respectively,

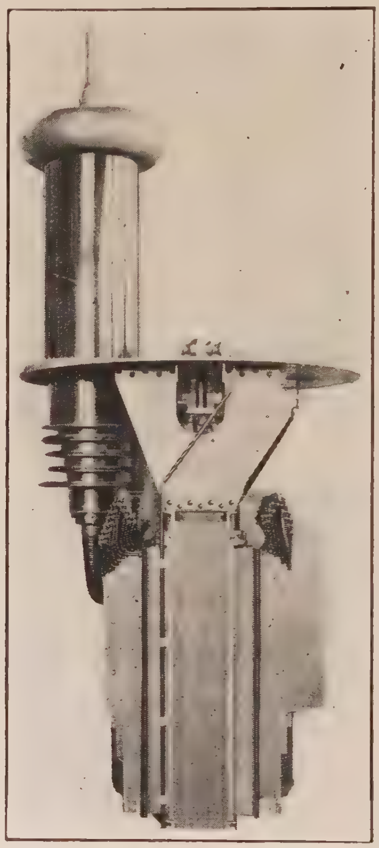


FIG. 5—VIEW OF THE HIGH-VOLTAGE TESTING TRANSFORMER

Removed from the case, facing edge-on the iron laminations and showing the tapered insulation on each side. Transformer 60 cycles, 500 kv-a., 578,000 to 2500 volts.

yet in spite of the difference in size the uniformity of style is apparent. Fig. 9 shows a collection of testing transformers and auxiliary apparatus of capacities from 3 kw., 30,000 volts to 300 kw., 300,000 volts, all of the same general design.

Figs. 10 and 11 show standard power transformers which closely resemble the testing transformers.

Winding and Insulation. The low-voltage winding consists of a single helical coil wound in one layer on an insulating cylinder closely fitting the central core leg. Both terminals are brought out at the bottom.

The high-voltage winding is composed of 50 double-section disk coils, each double coil being taped with varnished cloth, the insulation increasing toward the

top or line end. Two upper groups of coils are heavily taped as units also (see Fig. 4.).

In order to give a large radius to the upper corners

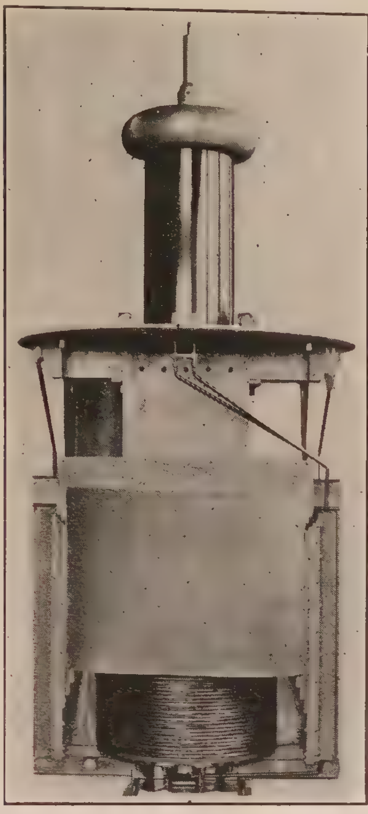


FIG. 6—VIEW OF THE HIGH-VOLTAGE TESTING TRANSFORMER

Removed from the case, facing the major insulation and showing how it covers the upper part of the high voltage coils. Transformer 60 cycles, 500 kv-a., 578,000 to 2500 volts.

of the coil stack, a thick, well-rounded wood ring or torus taped first with metal ribbon and then heavily insulated with varnished cloth tape is placed on top of

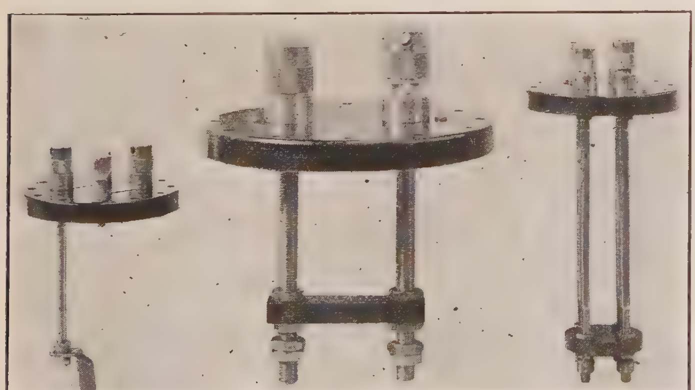


FIG. 7—LOW-TENSION TERMINAL BOARDS OF THE HIGH-TENSION TRANSFORMER

Film cut-out at the left. Low voltage in the middle and voltmeter coil terminal at the right.

the coil stack under the group taping and connected to the line terminal. This acts to prevent leakage over the major insulation and also as a static shield and arcing ring, the construction being virtually the same as in power transformers.

The size of the conductor, as well as the thickness of insulation between turns, sections, coils and the group insulation, increases toward the top and is very heavy near the line terminal in order to avoid short circuits from high-voltage, high-frequency line oscillations which, in a unit of this size, may be extremely severe.

The high-voltage winding contains about 30 miles of paper-covered aluminum strip.

All coils are in the form of thin disks, wound one turn per layer, the winding being subdivided into 100 single or 50 double coils.

The high-voltage conductor has a current capacity many times normal, being good for at least 5000 kv-a., but the material and cross section were determined by

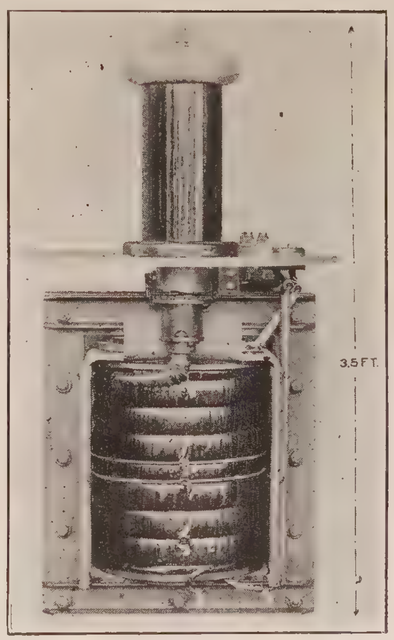


FIG. 8—A SMALL TESTING TRANSFORMER

5 kv-a. capacity, 50,000 volts to 100 and 220 volts. This picture is given to show the similarity between the small testing transformer and the large one previously described.

mechanical and electrostatic considerations and not by conductivity.

It was desired to obtain the maximum insulation and uniformity of winding, thus disk coils of one turn per layer were chosen, as on power transformers.

The outside diameter of the finished coils being large, it was necessary to use a large conductor for mechanical reasons to give stability to the coil while winding and handling. The paper covering may also be applied more successfully to conductors of considerable size, and a large radius on the edges is desirable for better insulation. Aluminum was used instead of copper chiefly to reduce the weight of the individual coils and thus to avoid injury during handling.

The resistance drop and losses in the high-voltage winding are negligible as is obvious.

The internal capacitance between turns, sections and coils is comparatively large as was intended, in order to distribute and reduce the dielectric stresses.

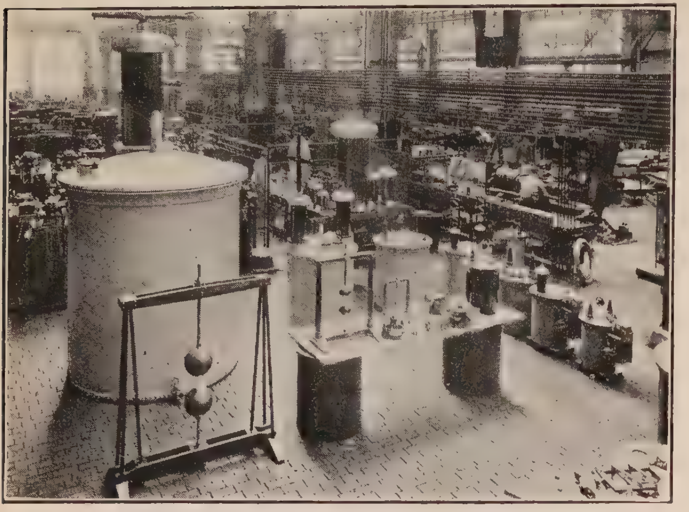


Fig. 9—Testing Transformer and Apparatus

In the foreground a collection of testing transformers, sphere gaps, and auxiliary apparatus ranging in capacity from 3 kw. at 30,000 volts to 300 kw. at 300,000 volts—all of the same general design.

The capacitance of the complete transformer is so great that the exciting current always leads the voltage and is much less than usual.

The calculated lagging magnetizing current is 46 amperes and the measured exciting current 33.5, corresponding to a leading current of 76 and an actual power factor at zero load of 0.445 leading. This is for a single unit at 2500 volts impressed.

When two units and the exciting transformer are connected for 1,000,000 volts to ground the power factor at the generator is 0.30 leading.

This is a favorable condition for the generator as the resultant current is greatly reduced and, being leading instead of lagging, the armature reaction is in conjunction with the field excitation instead of in opposition. The voltage wave-form, initially good, is distorted but little.

The actual capacitance being distributed in a complicated manner is difficult of calculation but a fictitious equivalent capacitance may be determined on the assumption that the internal capacitance is zero, and a condenser is connected in the high-voltage circuit at 578,000 volts, for one unit.

On this basis the high-tension current is 0.33 ampere (normal full load = 0.865) and the equivalent condenser has a capacitance of 0.0015 microfarad. This is the capacitance of about 35 ft. of one-inch cable with paper insulation one inch thick.

The actual current at the grounded end of the million-volt connection with no outside load is nearly

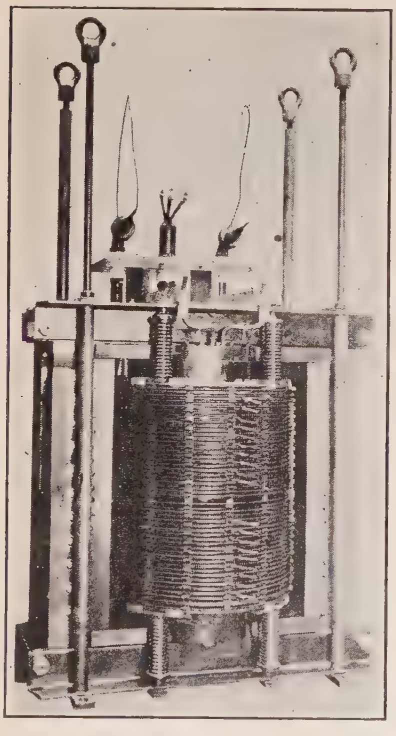


Fig. 10—A Standard Power Transformer for Comparison with a Testing Transformer

This power transformer is rated 25 cycles, 2500 kv-a., 100,000 volts to 6600 volts.

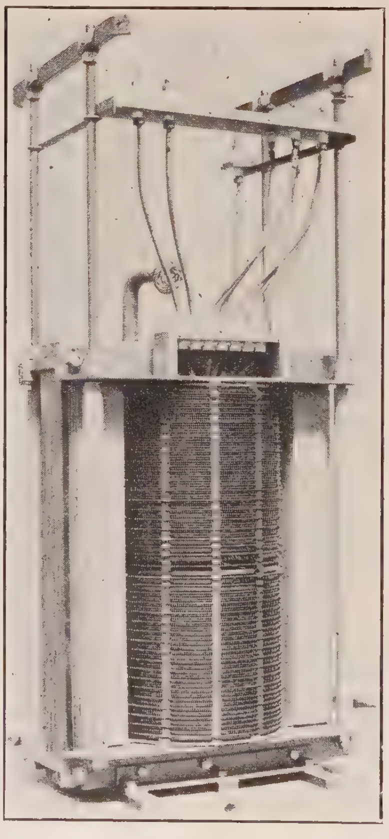


Fig. 11—Another Standard Power Transformer Showing the Likeness to the Testing Transformer

This power transformer is rated 60 cycles, 2500 kv-a., 69,360 to 120,000 volts Y.

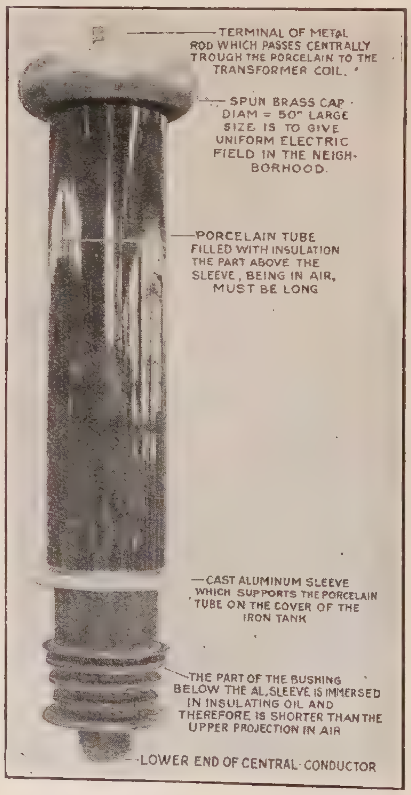


Fig. 12—High-Voltage Terminal

17 ft. 7 in. long, designed for 1,000,000 volts from line to ground and 500,000 volts from line to aluminum supporting sleeve.

0.5 ampere, which gives some idea of the capacitance effect.

Major Insulation. The insulation between low- and high-voltage windings consists of a series of concentric

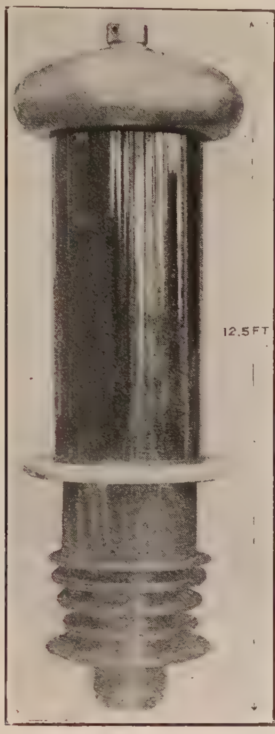


Fig. 13—High-Voltage Terminal

12 ft. 6 in. long, designed for 578,000 volts from line to grounded supporting sleeve.

insulating cylinders and oil spaces, provision being made for oil circulation. Moulded oil-treated pressboard shields of corresponding number and with similar oil spaces insulate the high-voltage winding from the core

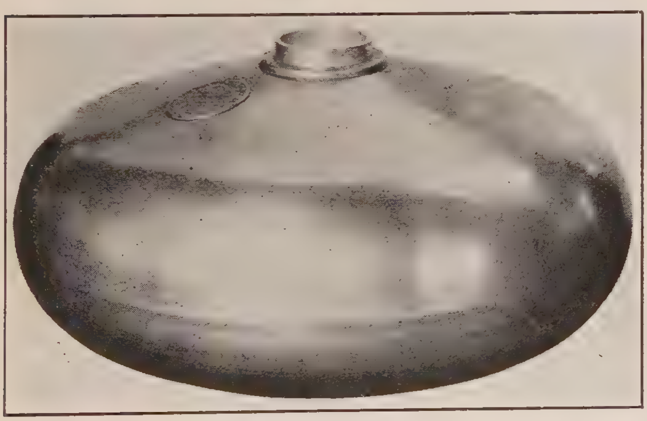


Fig. 14—Spun Brass Cap

50 in. in diameter, used on the high voltage terminal to give a uniform electric field and prevent corona discharge.

(Fig. 4). The number of cylinders, shields, and oil spaces increases toward the top, the insulation being tapered according to the voltage stresses, the total thickness being roughly proportional thereto (See Figs. 4 and 5). This arrangement is often referred to as "graded insulation" but the expression is incorrect, as "grading" refers to the use of several dielectrics of differing specific capacitance in series, to equalize the voltage gradient, as in concentric structures such as cables, and is not employed here. The insulation is "tapered", that is, the thickness varies with the voltage.

High Voltage Terminal. (Figs. 12 and 13)

This is of exactly the same design as the whole series of sizes used with testing transformers except for minor modifications made desirable by the extremely large size and high working voltage. The design of the whole series of sizes for working voltages of 50,000 to 600,000 was worked out expressly for testing transformers and standardized many years ago, so that intermediate or larger or smaller sizes may be calculated completely by empirical formulas with certainty that they will perform as expected.

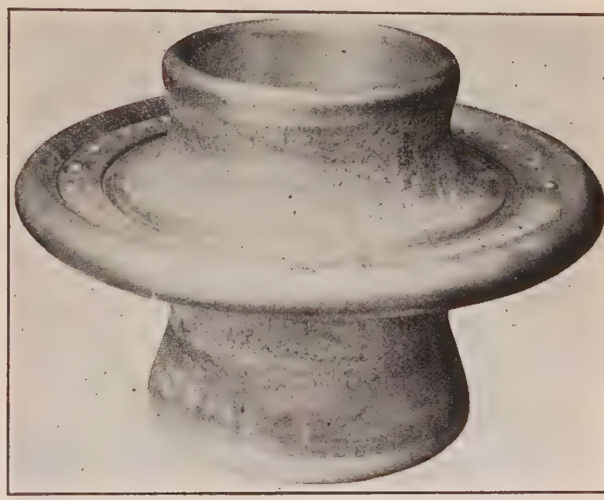


Fig. 15—Cast Aluminum Sleeve

Weight 715 pounds.

The terminals are of the filled type, the design being so efficient that corona is never shown, and the total length is a minimum.

The cap, (Figs. 14 and 12) 50 in. in diameter, is spun from brass sheet and nickel-plated. The cast-aluminum ground sleeve, 46 ½ in. in diameter, weighs 715 pounds (Figs. 15 and 12). The total length of the terminal (Fig. 13) is 12 ft. 6 ¼ in., for the 578,000-volt unit, and the calculated arcing voltage 640,000. This is reduced somewhat by the projections on the transformer cover.

The 1,000,000-volt terminal (Fig. 12) is essentially the same except in length, which is 17 ft. 6 7/8 in.

Insulating Transformer. (*Figs.* 16 *and* 17. *Location shown in Fig.* 1)

This is rated 500 kw., 2500 to 2500 volts, the secondary winding being insulated for a working voltage of 500,000.

Ordinary designs not being well adapted to the purpose, it was decided to use a form long in use for instru-

ment current transformers, although the capacity of this power transformer is about 1000 times greater.

The core consists of two stacks of sheet steel rings 33 in. outside diameter and without joints. The primary winding is of flat strip wound on the rings torus fashion in one layer which exactly covers the inner surface, giving a smooth, hollow cylinder well adapted for insulation from the secondary winding.

The major insulation is in the form of a pair of wall bushings passing through the two ring-shaped cores and closely resembling the terminal of the main units. The center of the bushing is a brass tube, the secondary winding passing through this and across the ends, forming a large rectangle of circular section. The whole

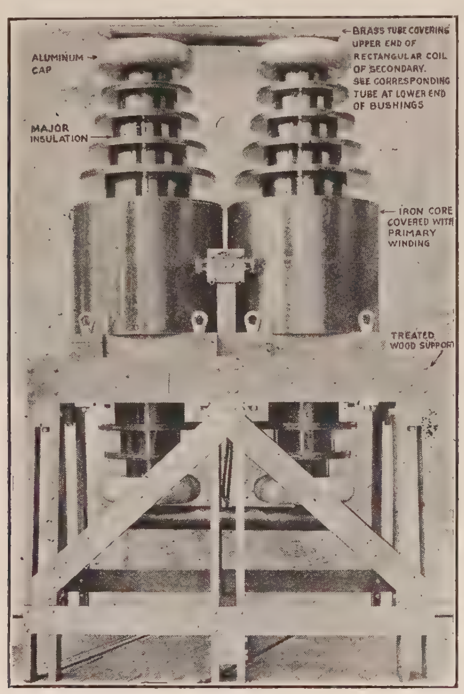


Fig. 16—Insulating Transformer Used in the Very High-Voltage Tests

Its rating is 60 cycles, 500 kv-a., 2500 volts to 2500 volts, but insulated for 500,000 volts.

stands on a treated wood support and is immersed in oil in the large open tank, the secondary being directly connected to the low-voltage winding of the insulated line unit and in metallic connection with the core of the latter and the "ground" sleeve of the million-volt terminal, as shown in Fig. 1. The torus-shaped caps of the wall bushings are of cast aluminum and of excellent form to avoid corona. The reactance of 17 per cent is low for a transformer of this extreme rating and is practically negligible for all ordinary service since the actual load is far below normal, while the short magnetic circuit and freedom from magnetic joints give low losses and exciting current.

Assembly for 1000 *Kv-a.,* 1,000,000 *Volts to Ground.* This is the most interesting connection, involving serious problems of design and construction, and is therefore shown in detail (Fig. 1). A large open oil tank, originally intended for experiments and tests

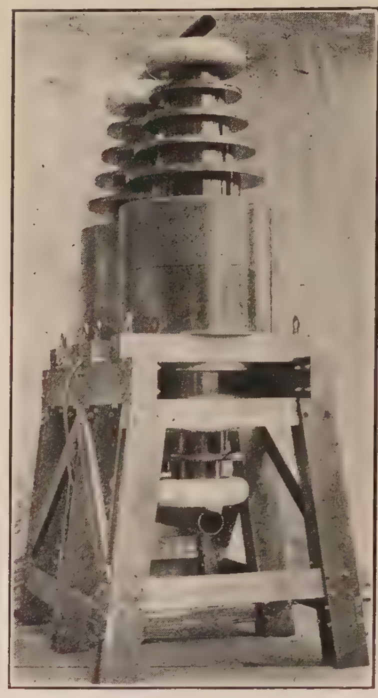


Fig. 17—Another View of the Insulating Transformer

under oil, was utilized for the insulating transformer, line unit and million-volt terminal, each being mounted on an insulating support made of treated wood.

Fig. 18—Two Separate Arc Discharges

The upper discharge, in the proper place between the terminal points, is made up of several successive arcs across a nine-foot gap between sharp points, and started by a million volts from line to ground. The lower discharge took place from the cap of the main terminal to a fence in the background. This accidental arc was photographed nearly end-on and does not indicate its length of 13 ft. The two strong lines near the arc show respectively the curved outline of the cap and the straight surface of the terminal by reflection from the arc. The location of this arc is shown in Fig. 19 at the point marked *A a*.

The tank is of boiler plate set in concrete and is 26 ft. long, 16 ft. wide, and 14 ft. deep, with semicircular ends, and holds 36,000 gallons of oil.

Voltage Measurements. The reactance of the main transformer units at 500 kv-a. each is 6 per cent and the conversion ratio at the usual low loads thus gives

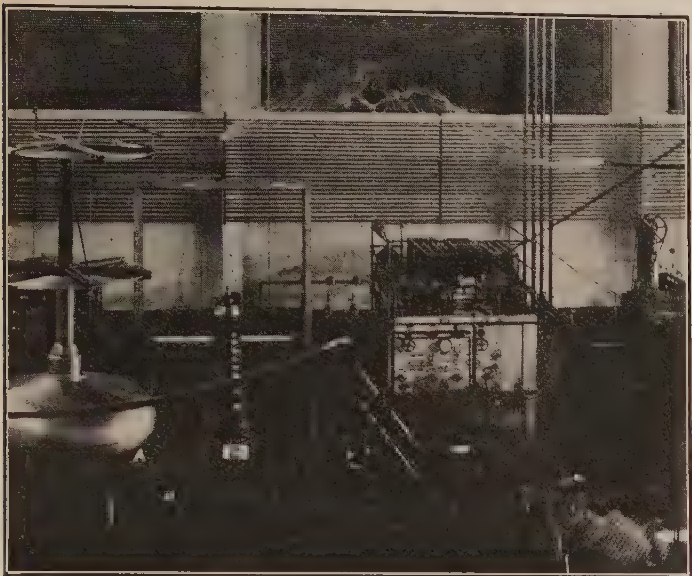


FIG. 19—A GENERAL VIEW OF THE HIGH-VOLTAGE TERMINAL

With its cap and two choke coils on the left and an arc nine feet long between sharp terminals. Spark voltage was a million volts effective from line to ground. The arc shows dimly, due to second exposure of the plate in daylight and poor focus.

a close approximation to the actual voltage. Full load is unlikely to be met with in testing practise. As a more accurate method, the voltmeter coil errors are less than 0.5 per cent at full-load, leading current and thus inappreciable at the usual loads of testing and experimental work. A sphere gap with diameter of one meter for each sphere is used for measurements up to a million volts above ground. This is designed in the form of swinging and sliding brackets, pivoted on the wall of the building, each bracket carrying a sphere, the axis of the spark gap being vertical. The two brackets or main frames hang in perfect balance at the ends of a silent chain passing over a sprocket mounted on ball bearings, and roll in a vertical direction on steel balls placed between *V*-shaped tracks of hardened steel attached to the main frames, and a 3½ in. steel shaft mounted on ball bearings attached to the wall.

Adjustment of the gap length is by means of an endless rope, pulleys and bevel gears which drive the sprocket on which the main frames are hung, and may be made while the apparatus is alive. The gap setting is indicated in millimeters on a large dial at the control board, the dial being operated by steel wires and bands connected to the main frames in a manner to avoid friction and backlash.

The spheres are spun from sheet aluminum, so that the weight carried by the main frames is a minimum. The frames are of treated wood and extend about 16 ft. from the wall. A high resistance composed of a large number of carborundum rods is hung from the roof trusses and connected between the upper sphere and ground.

The design permits exact and delicate adjustment under full voltage and the arcing distance may be read directly from the dial without error.

FIG. 20—SEVERAL SUCCESSIVE ARCS. BETWEEN POINTS SPACED 11 FEET (1,200,000 VOLTS)

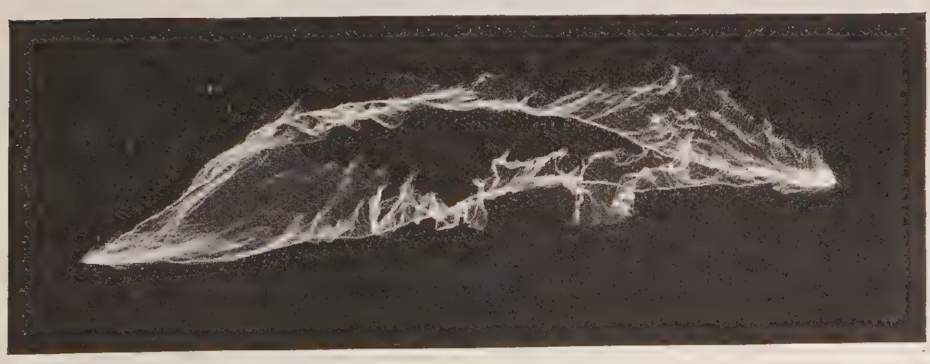


FIG. 21—TWO SUCCESSIVE DISCHARGES. BETWEEN POINTS SPACED 11 FEET (1,200,000 VOLTS)

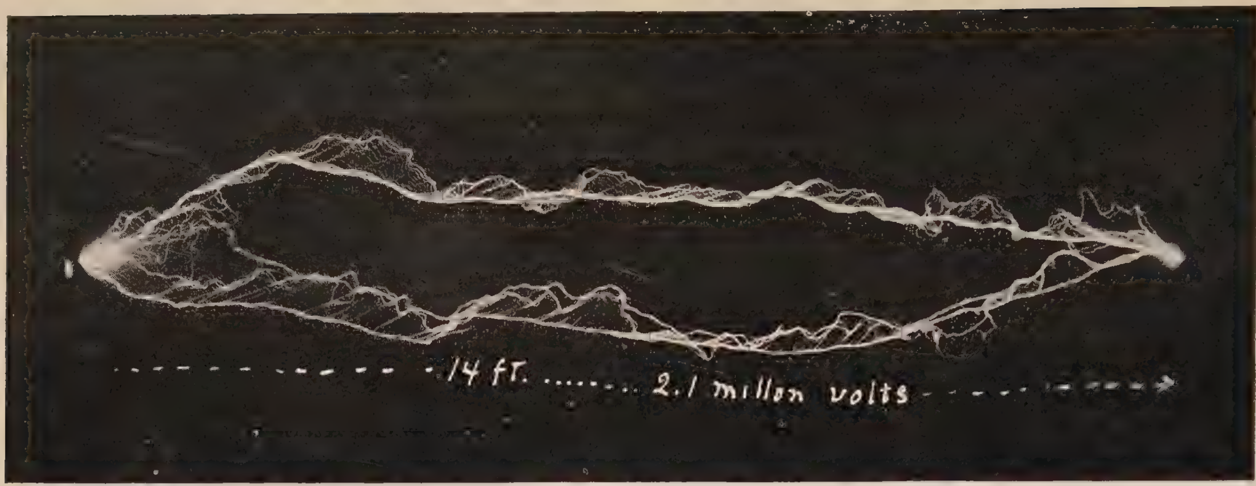


Fig. 22—Two Successive Discharges Between Points Spaced 11 Feet (1,500,000 Volts)
The left terminal is a million volts from ground. The right terminal is 500,000 volts from ground. Both terminals show brush discharge and two heavy spark discharges and about a dozen successive alternations of arc where the air currents have moved the arc in a direction parallel with the photographic plate.

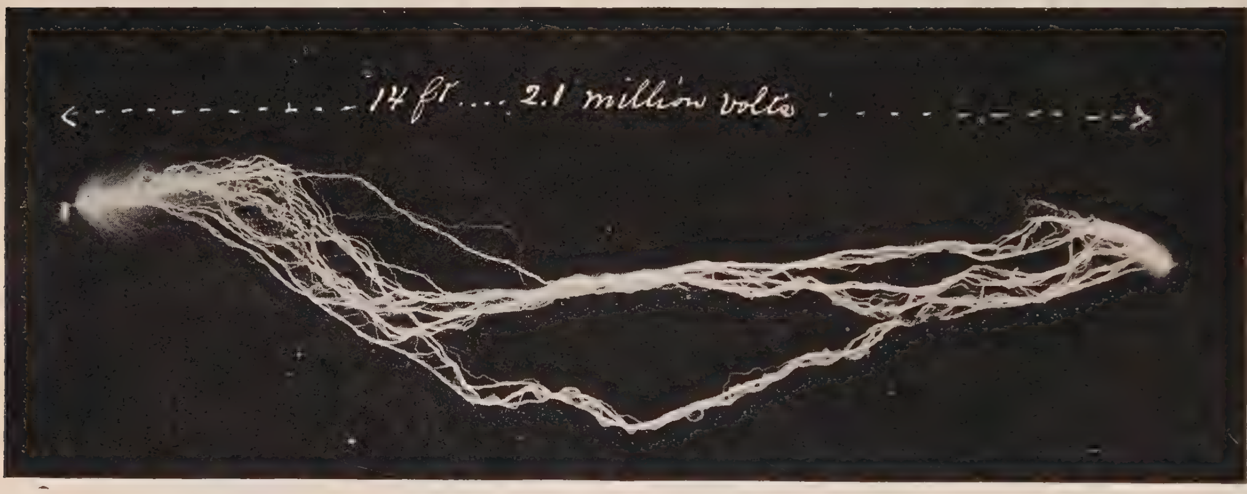


Fig. 23—A Second Record of a 14-Foot Gap
There were a number of successive arcs in this case and the brush discharge before the spark took place shows particularly strong on the left terminal.

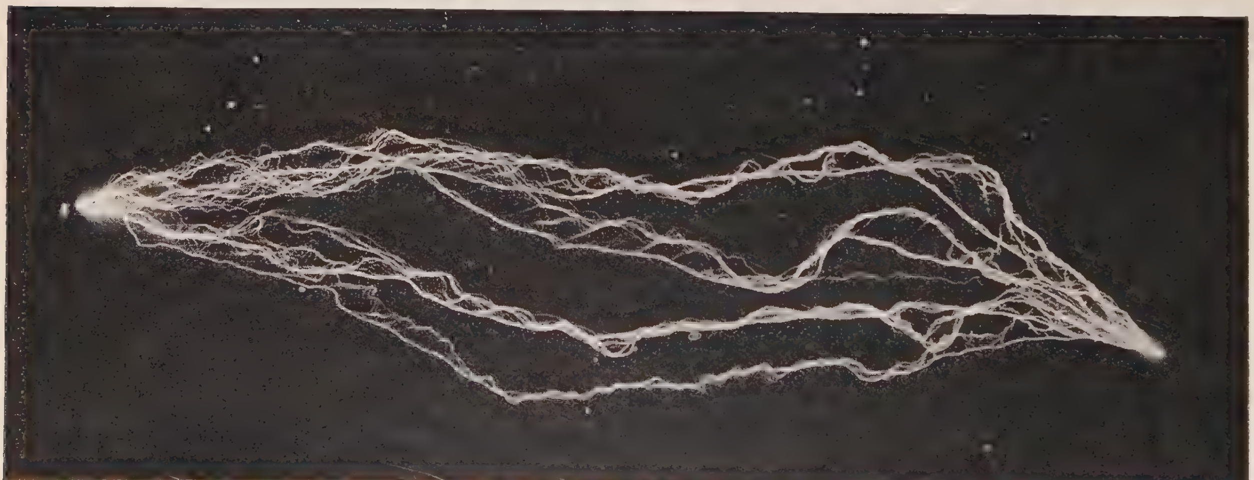


Fig. 24—A Third Record of a 14-Foot Gap
Again there were several successive discharges and a movement of the arc is recorded.

Since there are three identical main transformers any one may be used as a potential transformer, thus giving an additional check. However, the voltmeter coils are the most accurate and convenient means of determining the high voltage, regardless of reactance, load, phase relations, or atmospheric conditions. The chief variable is the amplitude factor of the potential wave, or the ratio of the crest to the effective value which is determined by the spark gap or by an oscillograph or crest voltmeter. This variation is small because of the excellent characteristics of the generator and the low flux densities and high capacitance of the transformers.

The spark gap is useful also in indicating the presence of transient voltages which are not easily determined in any other manner.

The voltmeter coil is of the differential form composed of two coils in series. The errors of the two coils are of opposite sign and the relative number of turns are so chosen as to give a minimum resultant error closely approaching zero. Other forms might have been used, but the differential coil lends itself more readily to exact calculation and may be placed near points at ground potential.

Other Connections. (a) The two transformer units in series for 1,160,000 volts with neutral grounded, (b) three units in series for 1,500,000 volts with the ground one-third the distance from one end, (c) as well as 1,000,000 volts, three-phase are all simple connections involving no serious problems.

The whole outfit, while it contains some novel features and unusual refinements of detail, is designed along well-tried and standardized lines, especially to meet local conditions, the requirements of routine commercial tests, experimental and research work.

Results

Fig. 18 shows several successive arcs across a nine-foot gap between sharp points at a million volts to ground. In making this test, the voltage was brought up steadily until an arc was formed. The current produced a large drop in generator voltage which broke the arc. The generator excitation was immediately increased by means of the field rheostat so that the voltage rose with a rush, too fast to be read on the voltmeter, and restarted the arc. A repetition of this phenomenon caused several more arcs to form and break in quick succession. The arcs, combined with a voltage increase of about 10 per cent, set up violent oscillations culminating in a high-frequency arc from the million-volt terminal cap to an iron fence, about 13 ft. distant. This arc is shown in the lower left-hand corner of the picture and, being viewed nearly end-on, does not appear in its real length.

The outline of a portion of the terminal cap and cylinder is shown by reflection, and the actual position is given in the corresponding general view of the apparatus, Fig. 19. The nine-foot arc between points in Fig. 19 does not show clearly because the negative was exposed twice, once by daylight for the room and once in the dark for the arc and was not exactly in focus.

A resistance of about 525,000 ohms was in series with the main nine-foot arc, thereby limiting the current in this part of the circuit, but obviously there was no ohmic resistance to limit the discharge from the cap to the fence. As a result this arc was of explosive violence and of extreme brilliancy.

In another test at 1,000,000 volts to ground a discharge was formed from one of the choke coils located above the terminal cap (Fig. 1) to an iron pipe on the wall of the building. The spark distance was about 18 ft. and therefore, on the basis of voltage being proportional to length, represents an instantaneous potential to ground of about 2,750,000 volts.

Fig. 20 shows a series of eleven-foot arcs at about 1,200,000 volts between points with neutral grounded, and about 525,000 ohms in the circuit on one side of the gap.

Fig. 21 shows two successive arcs taken under the same conditions.

Figs. 22, 23 and 24 show fourteen-foot arcs at about 1,500,000 volts between points with about 400,000 ohms in the circuit on one side of the gap. Three transformer units were connected in series for this test, the grounded point being 1,000,000 volts from one end and 500,000 volts from the other end.

(*To be continued*)

A NEW TYPE OF WATER FLOW INDICATOR FOR TRANSFORMERS

BY A. M. ROSSMAN
Associate, A. I. E. E.
Sargent & Lundy, Chicago, Ill.

The water-flow indicator herein described consists of a heavy cone-shaped metal plunger floating in a circular orifice. A change in the amount of water flow demands a corresponding change in the free area of the orifice and this is obtained by a vertical movement of the plunger in the orifice. This movement is transmitted through a bell crank and shaft to an external pointer which moves over a scale, calibrated in gallons of flow per minute. A number of these indicators has been in successful operation in several different states since the summer of 1920.

The water-flow indicator herein described was developed primarily to provide a simple and dependable means of indicating the quantity of water flowing through the coils of a water-cooled transformer.

As shown in Fig. 1, the principal moving part is a heavy conical shaped metal plunger which is free to move vertically through a circular orifice. Such a movement produces a change in the free area of the orifice which is inversely proportional to the increase or decrease in the cross sectional area of that part of the plunger which lies in the plane of the orifice. When

water is admitted below the plunger it causes the plunger to rise and take a position corresponding to the quantity of water flowing. When no water is flowing, the weight of the plunger causes it to assume its lowest position where it practically closes the orifice. Calibration tests made on one body with several plungers of different degrees of taper show that the plunger tends to assume a position such that the free area of the orifice is almost directly proportional to the quantity of water flowing.

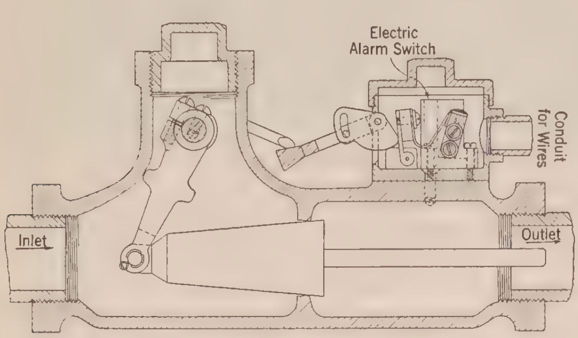


Fig. 1

The plunger is loosely pivoted to one arm of a bell crank. The shaft which carries this arm passes through a gland in the wall of the housing and carries a pointer on its external end. A movement of the plunger is thereby transmitted to the pointer which describes an arc over a scale, calibrated in gallons of flow per minute. A second external arm closes a switch and sounds an alarm when the flow falls below an adjustable, predetermined minimum value.

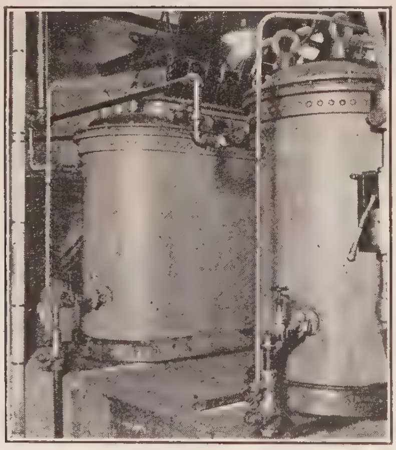


Fig. 2

It will be noted from Fig. 1 that after the water flow is once established, the plunger cannot stick in the orifice because it is free to float in the stream of liquid, unhampered by any form of lateral restraint. Furthermore, there is small likelihood of the orifice becoming clogged, due to the gradual building up of a deposit of foreign matter, because the high velocity of the water through the orifice tends to scour the surfaces of both the orifice and the plunger, thereby preventing the accumulation of foreign matter. This cleaning process is further assisted by the constant lateral movement of the plunger and its occasional vertical movement during inspection or readjustment of the flow.

In calibrating these devices it is found that the same curve is obtained irrespective of whether the flow is adjusted by a valve located in the inlet or in the outlet pipe. Furthermore, the calibration curve, obtained by starting with zero flow and increasing to the highest point of the scale, is practically the same as the curve obtained by starting with the maximum flow and decreasing to zero, thereby showing that the friction between the shaft and the gland is small compared with the torque due to the heavy plunger.

Several of these devices have been in continuous service on transformers in the central and southwestern states since the summer of 1920, without receiving any attention other than routine inspection. One of these, after being in service several months on water which carries a large amount of suspended matter, was opened up for inspection, and it was found that the plunger and the entire inside surface of the housing as well as the interior of the piping system were coated with a green slimy fungus growth to a depth in some places of 1/8 in. This deposit apparently had no detrimental effect on the operation of the indicator, although it may have affected its calibration by restricting the free area of the orifice. A later inspection, made shortly after the transformer-cooling water was changed from raw to treated water, showed that this fungus coating had practically disappeared.

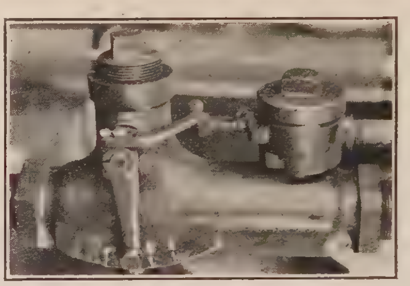


Fig. 3

The operators at the different stations at which these indicators are installed have been quick to learn that they can easily "feel out" the operation of the indicator by lifting or forcing down the pointer and then releasing it and allowing it to come to rest at its original position. This is an almost infallible test of whether or not the plunger is floating properly in the water circuit.

While developed primarily for use on water-cooled transformers this indicator is adaptable to many other applications, involving the measurement of the flow of liquids in pipes. Figs. 2 and 3 show them installed in commercial service on water-cooled transformers.

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Changes of advertising copy should reach this office by the 15th of the month for the issue of the following month.

New Edition of Standards of A. I. E. E.

A new edition of the Standards of the American Institute of Electrical Engineers has just been issued. In this 1922 revision of the Rules are incorporated changes and additions the scope of which is outlined below. The Standards, comprising approximately 180 pages are bound in flexible leather covers. The price is $2.00 per copy, with 20 per cent discount to A. I. E. E. members, dealers and purchasers of ten or more copies. Address all orders to Secretary A. I. E. E., 33 West 39th St., New York.

SCOPE OF THE 1922 REVISION

The 1922 revision of these standards is in most respects substantially a reprint of the 1921 edition, but some additions and modifications have been made, the most important of which are indicated below.

The most important change is the inclusion of a new Chapter X presenting Standards for Storage Batteries. It is believed these standards are of considerable value in establishing standard methods of rating for storage batteries.

In Chapter I an additional class of insulating materials has been provided, namely, "Class O—Cotton, silk, paper and similar materials when neither impregnated nor immersed in oil."

In Chapter III definitions have been given of "power factor," distinguishing between "momentary" and "average" power factor, and of the "normal voltage of a system."

The term "Oersted" has been adopted for the unit of magnetic reluctance, and the term "electrical tension" has been adopted for use as an alternative to "voltage" in cases where the electric potential is not expressed in volts.

In Chapter VI a distinction is made between "full capacity taps" and "reduced capacity taps" of transformers.

To Chapter VII there have been added a considerable number of definitions of different types of electric protective relays and of the qualifying terms applied to them. A slight modification has been made in the temperature limits for circuit breakers, relays and switches.

In Chapter VIII the Corona voltmeter is recognized as a satisfactory form of crest voltmeter.

To Chapter XII have been added a number of definitions, for the most part referring to machine switching telephone apparatus.

Future Section Meetings

Akron.—October 24, 1922. Engineering Hall, University of Akron. Subject: "The Portable Oscillograph" (with a demonstration of the instrument). Speaker: Mr. J. W. Legg, of the Westinghouse Electric Mfg. Company.

Worcester.—October 19, 1922. Mr. C. F. Hood, of the American Steel & Wire Company, Worcester, will present a paper on the Manufacture of Wire.

Industrial Engineers' Convention

The Society of Industrial Engineers will hold a three-day national convention in New York beginning October 18. Prof. Joseph W. Roe, president of the Society, and head of the Department of Industrial Engineering at New York University, will preside.

"Economics of Industry" will be the general topic of the the convention, which will be attended by leading industrial engineers and members of the faculties of leading universities from all parts of the country. The engineers will meet at the Hotel McAlpin.

Barton T. Bean of San Francisco, Harrington Emerson of New York, and W. G. Sheehan of Detroit have been elected directors of the Society to serve five years.

On the evening before the convention, there will be a joint meeting of the society, with the Taylor Society and the American Society of Mechanical Engineers. The national headquarters of the Industrial Engineers are in Chicago.

Eight-hour Versus Twelve-hour Shift in Industry

The Committee on Work-Periods of the American Engineering Council of the Federated American Engineering Societies has made extensive investigations through its members as to the relative prevalence and efficiency of the two- and three-shift work period. The report finds that the eight-hour shift is in successful operation and compares favorably with the longer shift in amount of production, tends to strengthen morale, lessen shirking and tardiness, etc., and in general produces as good or better results for the employers, with obvious advantages to the employees.

Muscle Shoals from the Engineers' Viewpoint

At a meeting of the Executive Board of the American Engineering Council at Boston, September 8th, the Federated Association of Engineering Societies appointed a committee to investigate thoroughly every phase of the Muscle Shoals proposition from the engineering standpoint, so that the public may have a concise, disinterested statement of facts. This entails a great piece of volunteer work on the part of the engineers appointed, the results of which will doubtless be of far reaching importance in clearing up the situation. Calvert Townley, past-president of the American Institute of Electrical Engineers, is chairman of the Committee on Procedure. Other members are Dexter S. Kimball, president of the American Society of Mechanical Engineers, J. Parke Channing, W. E. Rolfe, W. W. Varney and H. E. Howe.

PERSONAL MENTION

F. W. Molitor has resumed teaching at the Arsenal Technical Schools, following a summer's engagement with the Bureau of Standards.

H. A. Hoffman has resigned from the Eynon-Evans Corporation, Philadelphia, and is connected with the Elliott Company, Haas-Howell Building, Atlanta, Ga.

W. C. Beckjord, has resigned from the St. Paul Gas Light Company and is now with the American Light & Traction Company, 120 Broadway, New York, N. Y.

Harry F. Dart, formerly Instructor in Electrical Engineering, Harvard University, is now engaged in research work for the Westinghouse Lamp Company, Bloomfield, N. J.

Harold Calvert has terminated his work with the Philadelphia Electric Company to accept the position of President of the Baird-Osterhout Company, Philadelphia, Pa.

George Southgate has given up his position with the Bureau of Soils, Washington, D. C. to accept a position with the Federal Phosphorous Company, Brown-Marx Building, Birmingham, Ala.

Irving W. Edwards, formerly connected with the National Carbon Company, where he was Brush Sales Engineer, has resigned to organize his own business, 220 Broadway, New York, N. Y.

Laurence E. Frost has resigned from the Western Electric Company and has taken a position with the Brooklyn Edison Company, where he will be Technical Assistant to the Electrical Engineer.

Frank Kerswell has resigned as Chief Electrician, Southern Pacific Lines in Mexico and is now Electrical Foreman, Main Shops, St. Louis-San Francisco Railway, with headquarters at Springfield, Mo.

F. G. McRae severed his connection with the Willys Light Systems, where he was Engineer, Secretary and Treasurer, to become Sales Engineer for Electric Service Supplies, 610 Monadnock Building, Chicago, Ill.

A. D. Holmes, formerly with the New England Power Company has resigned his position as Superintendent of the Uxbridge Steam Plant to become associated with the Central Maine Power Company located at Gardiner, Me.

C. E. Reese, formerly Editor of the *Gas Engineering & Appliance Catalogue* and Associate Editor of the *Gas Age-Record*, has joined Stoker Sales Department of the Westinghouse Electric & Mfg. Company, South Philadelphia, Pa.

H. H. Metzenheim became Instructor in the Department of Electricity of the Newark Technical School, Newark, N. J., February 1, 1922. He was formerly with the Crocker-Wheeler Company, Ampere, N. J., as Assistant D. C. Designer.

Chester A. Corney, formerly connected with the Electrical Engineering Department of Stone & Webster, 147 Milk St., Boston, has joined the Electrical Engineering Department of the Edison Electric Illuminating Co., 39 Boylston St., Boston, Mass.

Roy E. Heffner, until recently Instructor in the Department of Electrical Engineering, Cornell University, has become affiliated with John B. Stetson University, Deland, Fla., where he will teach in the engineering college newly organized there.

John W. Lieb, Fellow and past-president of the American Institute of Electrical Engineers and Vice-President of the New York Edison Company, has been imformed that the King of Italy has bestowed upon him the decoration of Grand Officer of the Royal Order of the Crown of Italy. Dr. Lieb had already been made Knight Commander of the Crown of Italy for notable electrical work in Italy some years ago.

T. M. Feder, Associate of the A. I. E. E., has been appointed Special Representative of the Illinois Electric Porcelain Company, Macomb, Illinois. He will be chiefly interested in the development of the high tension business of the company. Mr. Feder is a graduate of the Brooklyn Polytechnic Institute, where he was later an instructor. He was previously connected with the New York office of the Esterline-Angus Company.

W. S. Rugg, Assistant to the Vice President of the Westinghouse Electric and Manufacturing Company, has been made General Sales Manager of that Company. Mr. Rugg is the first to hold this position, coming to him as a result of his broad experience and remarkable success in this kind of work in which he has been engaged for many years. He became associated with the Westinghouse Electric & Manufacturing Company in 1892 at Pittsburgh. Later, he was transferred to the Chicago office as District Office Engineer, later becoming a salesman, and was promoted by successive steps to Assistant to the Vice President in 1920. Mr. Rugg is a member of the American Institute of Electrical Engineers, the National Electric Light Association, the American Electric Railway Association, the Franklin Institute, the American Association for the Advancement of Science and the Engineers Club of New York.

Obituary

Merritt B. Miller, an Associate of the American Institute of Electrical Engineers, was accidently killed by electric shock at Saugatuck, Michigan, on August 16th. He was born August 24, 1894 at Rockford, Ill., received his early education at Alma, Mich., and attended Purdue University where he studied electrical and mechanical engineering. He was engaged in electrical work until the outbreak of the war, when he became an officer in the Army. After the war he resumed electrical work, and at the time of his death was Engineer for the Central Michigan Light and Power Company, Alma, Mich.

Gisbert Kapp, the distinguished English electrical engineer, died at his home in Birmingham, England, on August 10th. His eminence as a pioneer in the electrical engineering world is recognized internationally.

Mr. Kapp was born near Vienna, where he spent his early youth. While still very young he moved to England, and it was in that country that he did the greater part of his work. He did valuable designing in mechanical and electrical machinery for a number of years; afterward he accepting the position of Secretary of the Association of Electrical Engineers of Germany, in which capacity he did useful work. Later he accepted the professorship of electrical engineering at the University of Birmingham. While teaching here he published "Principles of Electrical Engineering" the last of his published works. He was one of the first engineers to understand and expound the theory of alternating currents, and on this subject he was a recognized authority.

Mr. Kapp was the recipient of many honors. He was a Telford medalist, he was made honorary doctor of engineering, was president of the British Institution of Electrical Engineers, and president of the Engineering Section of the British Association for the Advancement of Science. He is survived by two sons, both of whom are engineers.

F. A. E. S. Bulletin

The Federated American Engineering Societies issued the first number of their *Bulletin* on September 1. It is a monthly publication covering the activities of the F. A. E. S., carries an editorial column and contains news of interest to engineers.

Engineering Societies Library

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is administered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 6 p. m.

BOOK NOTICES (AUGUST 1-31. 1922)

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statements made; these are taken from the preface or the text of the book.

All the books listed may be consulted in the Engineering Societies Library.

Les Applications Elementaires des Fonctions Hyperboliques a la Science de L'Ingenieur Electricien.

Par A. E. Kennelly, Paris, Gauthier-Villars et Cie, 1922. 153 pp., diagrs., 9 x 6 in., paper.

Dr. Kennelly spent the academic year 1921-22 as an exchange professor in France, where he delivered a course of lectures at universities and engineering schools upon the applications of hyperbolic functions to electrical engineering problems. This monograph, based upon these lectures, places before the French student, in abridged form, the material already published in English by the author.

Design of Masonry Structures and Foundations.

By Clement C. Williams. First edition. N. Y. and Lond., McGraw-Hill Book Co., 1922. 555 pp., illus., diagrs., 9 x 6 in., cloth. $5.00.

Recent analytical and experimental investigations of the properties of masonry materials, the forces to which masonry structures are subjected and the behavior of such structures have contributed largely to the transformation of masonry design and construction from an art to a science. The extensive use of concrete and the development of reinforced concrete have contributed largely to this end. This scientific understanding of masonry design has widened the use of masonry to include many structures for which other materials were formerly used. In addition, more attention is being paid to elegance, grace and beauty in design.

This volume is prepared to furnish a textbook embodying these ideas. An attempt has been made to offer a method of analyzing forces and calculating the resulting stresses and to indicate an acceptable method of design, without extended discussion of questions of interest to engineers rather than students. An effort has been made to keep in mind the aesthetic features of design.

Industrial Physics; Mechanics.

By L. Raymond Smith. First edition. N. Y. and Lond., McGraw-Hill Book Co., Inc., 1922. 226 pp., illus., diagrs., 8 x 5 in., cloth. $1.75.

The present trend in education has created a demand for textbooks in which the material presented is closely connected with the every-day life of the student. This volume is an attempt to meet this demand by providing an elementary, practical textbook on mechanics, suitable for use in high schools and vocational schools.

Standard Handbook for Electrical Engineers.

Frank F. Fowle, editor-in-chief. Fifth edition, revised. N. Y. and Lond., McGraw-Hill Book Co., 1922. 2137 pp., diagrs., 7 x 4 in., fabrikoid. $6.00.

As the last edition of this popular handbook appeared seven years ago, this revision, which takes account of the many new developments since that time, will be widely welcomed. No change has been made in the general arrangement and make-up, but each section has been thoroughly revised by the substitution of modern material and data for such as had become obsolete. Substantial changes have been made in almost every section, a few have been rewritten, and new material has been added to others.

L'Union D'Electricite et La Centrale de Gennevillers.

By Ernest Mercier. Paris, La Revue Industrielle, 1922. 48 pp., illus., plates, 12 x 9 in., paper.

The Union Francaise d'Electricité, formed in 1919, is a combination of the principal central stations serving Paris and its environs, organized to unify the systems of distribution in existence, to eliminate competition between its organizers and to provide for the future in a rational way. This monograph describes the distributing system adopted and the generating stations acquired. The principal portion of the book is devoted to the new power plant under construction at Gennevilliers, planned for a present output of 200,000 kilowatts, with future enlargement to 320,000 kilowatts. This station is described in detail. Many plans and illustrations are given.

World Metric Standardization.

Compiled by Aubrey Drury. San Francisco, World Metric Standardization Council, 1922. 524 pp., ports., 9 x 6 in., cloth. $5.00.

A comprehensive survey of the arguments advanced in favor of the adoption of the metric system in commerce. The testimony of proponents of the system has been collected from a wide range of sources and summarized in convenient form for consultation. A bibliography of over fifty pages is included.

Hydraulics with Working Tables.

By E. S. Bellasia. Third edition. N. Y., E. P. Dutton & Co., 1922. 348 pp., tables, illus., 9 x 6 in., cloth. $8.00.

In this edition the book has been brought thoroughly up to date and subjected to careful and drastic revision. The chief object, is, as before, to deal thoroughly with the facts, laws and principles of hydraulics, and to keep always in view their practical aspects. Fresh discussions on all the most important coefficients are now given and specific recommendations are made. A new set of coefficients for pipes is given.

Fresh matter has been added on weirs and weir-like conditions, on discharge measurement by means of pipe diaphragms, on standing waves and on the laws governing silting and scour. The book is intended to meet all the requirements both of the student and of the engineer.

Addresses Wanted

A list of members whose mail has been returned by the Postal Authorities is given below, together with the addresses as they now appear on the Institute records. Any member knowing the present address of any of these members is requested to communicate with the Secretary at 33 West 39th Street.

1.—W. S. Guilford, Box 1075, Capetown, S. Africa.
2.—Tadashi. Iida, 400 Wilson Street, Joliet, Ill.
3.—William Lewis, 31 West 4th Ave., Huntington, W. Va.
4.—Geo. B. Rodgers, 30 East 21st Street, New York, N. Y.
5.—Robert C. Scott, Box 464, Dundas, Ontario, Canada.

Employment Service Bulletin

OPPORTUNITIES.—Desirable opportunities for service from responsible sources are announced in this Bulletin, and no charge therefor is made.

MEN AVAILABLE.—Under this heading brief announcements (not more than fifty words) will be published without charge to the members. Announcements will not be repeated except upon request received after a period of three months, during which period names and records will remain in the active files.

NOTE.—Notices for the JOURNAL ***should be addressed to EMPLOYMENT SERVICE, 33 West 39th Street, New York, N. Y.,*** *the employment clearing house of the National Societies of Civil, Mechanical, Mining and Electrical Engineers.*

Notices for the JOURNAL are not acknowledged by personal letter, but if received prior to the 16th of the month will appear in the issue of the following month.

All replies to either "Opportunities" or "Services Available" should be addressed to the key number indicated in each case ***and forwarded to EMPLOYMENT SERVICE,*** *as above.*

Replies received by the bureau after the position to which they refer has been filled will not be forwarded, and will be held by the bureau for one month only.

OPPORTUNITIES

RADIO AND ELECTRICAL ENGINEER wanted to take charge of sales and development work of radio and electric wiring device specialties. Splendid opportunity for ambitious young man to make his own future. Application by letter. Salary not stated. Location, New York City. V-1900.

INSTRUCTOR in mathematics, including descriptive geometry and surveying. Appointment for three years beginning Sept. 1922. Recent graduate of some good engineering school preferred. Appointment by letter. Salary $600 year and expenses. Location, Syria. V-1929.

ENGINEER with substation, switchboard, transmission line experience, etc. to act as squad boss. Application by letter. Salary not stated. Location, New York City. V-2150.

LOCAL MANAGER for power plants for towns 5000-15,000 population. Application by letter. Salary $1800-3600. Location not stated. V-2228.

SALES MANAGER with sales experience in conveying machinery. Company manufactures roller gravity, belt conveyors, industrial and vertical automatic elevators, slides, shutes, etc. Application by letter. Salary not stated. Location, New York City. V-2333.

ASSOCIATE EDITOR for engineering journal. General qualifications: Age 28-35; engineering education, preferably mechanical; shop experience preferably as an executive; some editorial experience or its equivalent; personality, the ability to mix. Application by letter. Salary not stated. Location, New York City. V-2117.

CHEMICAL ENGINEER who has had actual experience in putting up naphthalene plants. Application by letter. Salary not stated. Location, New York City. V-1627.

SALES ENGINEER. Young single man having practical experience with detail electrical switchboard apparatus, such as circuit breakers and instruments. Sales experience not necessary. State age, experience and salary expected. Location, Philadelphia territory. V-1683.

ELECTRICAL DRAFTSMAN, experienced in power house substation and switchboard design and layout. Application by letter stating education, experience and salary expected. Send photograph if possible. Location, Ill. V-1829.

TRANSFORMER DESIGNING ENGINEER with well known British firm of electrical engineers. Must have had first class experience in design and manufacturing of large high tension transformers. Application by letter giving full particulars of experience. Salary not stated. Location, England. V-1830.

DRAFTSMEN (12 or 15) to place in steam turbine department, preferably those who have had a technical education and at least 5 years experience on steam work. Application by letter. Salary not stated. Location, Mass. V-1838.

SUPERINTENDENT of foundry laboratory in large university in middle west. Fine opportunity for technically trained man with foundry experience who desires to enter teaching profession. Application by letter. V-1881.

ELECTRICAL ENGINEERS (2) as sales engineers in machinery company. Should be single and have practical shop experience, and one or two years office experience preferably in General Electric Company. Preference given to men who speak Spanish. Should be prepared to make future with company in South America. Transportation to South America paid. Application by letter. Location, Chile. V-1882.

TECHNICAL MECHANICAL ENGINEER who has had four or five years power engineering experience, testing of power plant apparatus and consumption of steam, air, water, electricity, etc. of industrial plant equipment. An engineer with considerable tact and diplomacy wherewith he can, in the prosecution of his work, enlist the cooperation of plant operatives over whom he would have no direct authority. Application by letter. Salary not stated. Location, Delaware. V-1906.

CHIEF DRAFTSMEN for company manufacturing air compressors. Twelve inch stroke and shorter; steam and power pumps, twelve inch stroke and shorter. Need man who can keep line up-to-date. Application by letter. Location, Illinois. V-1910.

ELECTRICIAN practical and capable of laying out work. Must be willing and able to do house wiring, etc. himself when necessary. Excellent opportunity. Application by letter. Salary not stated. Location, Yonkers, N. Y. V-1931.

MILL SUPERINTENDENT. Capable technical engineer with several years experience in manufacture of wire and cable, especially paper lead power cable. Application by letter. Salary not stated. Location, New York City. V-1943.

YOUNG MECHANICAL ENGINEER with 2-4 years practical experience in some chemical industry for experimental and research work in solving problems for various departments of textile plant. Salary not stated. Application by letter. Location, Western N. Y. V-1954.

SALES ENGINEER experienced in handling overhead cranes, trench excavators and gasoline shovels. Should be experienced on gas engines. Single man not over 30 years old. Application by letter. Location, New York City. V-1955.

ENGINEERS specialized in manufacture and installation of electrical panel boards and steel cabinets. Competent to design and supervise the manufacturing of distribution centers are especially desired. Salary not stated. Application by letter. Headquarters, Pa. V-1962.

ELECTRICAL DRAFTSMAN. Need not be college graduate but rather one who has had drafting and some construction experience. Should have had sufficient practical experience to familiarize him with apparatus used in power plant and substation construction and sufficient experience to know what is required to make a finished drawing. Salary not stated. Application by letter. Location, Pa. V-1964.

ESTIMATOR. Designer, preferably with experience in consulting engineer's office on power generating equipment. Must be capable of making plant survey to determine power requirements for extensive new installations. Application by letter. Salary not stated. Location, Ohio. V-1981.

GRADUATE ELECTRICAL ENGINEER for Commercial Dept. Good personality and experienced in selling electric power to industrial concerns. Application by letter. Location, New York state. V-1985.

HIGH-GRADE SALES REPRESENTATIVES (2) men with mechanical knowledge, to act as special sales representatives in assisting branch managers analyze and promote sale of motor trucks to (1) oil and gasoline industries (2) packing, wholesale grocery and food products. Must have thorough knowledge of and wide acquaintance with executives of one of the above industries, and travel extensively. Application by letter giving personal characteristics, business experience in detail, salary expected and date available. Headquarters, Ohio. Salary not stated. V-1993.

YOUNG ELECTRICAL ENGINEER with practical experience along construction and designing lines for position as Assistant to Electrical Engineer in connection with development and construction on high tension system. Experience in transmission and power plant work essential. Good future. Application by letter enclosing recent photograph. Salary not stated. Location, Pa. V-2016.

TEST ENGINEER for power station. Mechanical Engineer with one or two years power house experience on oil as fuel, and competent in analysis of boiler water and flue gases. Application by letter. Location, Chile. V-2029. (3 yr. contract.)

ELECTRICAL ENGINEER, recent graduate, for testing, estimating and general layout work in connection with large underground distribution system. Application by letter. Salary not stated. Location, Nebraska. V-2055.

ASSOCIATE PROFESSORSHIP in Electrical Engineering. Application by letter. Location, Texas. V-2064.

ELECTRICAL ENGINEER capable of directing the operation of transmission lines and stations over a territory 75 miles in extent. There will be three assistants to handle the shift work. Application by letter. Location, N. Y. State. V-2066.

MECHANICAL ENGINEER experienced on design and test along power plant and steam apparatus lines. Operation experience desirable. Application by letter. Location, N. Y. C. V-2069.

ELECTRICAL ENGINEER with at least two years' practical experience, for work on design and construction of electric locomotives and car equipments. Application by letter giving age, education, experience and three references. Salary not stated. Location, Pa. V-2076.

ELECTRICAL ENGINEER with some practical experience to act as instructor. Must be graduate of first class technical school. Application by letter. Location, Maine. V-2096.

HIGH GRADE SALES EXECUTIVE with broad knowledge of industrial field to carry on an educational industrial campaign among manufacturers; complete details required. Application by letter. Headquarters, N. Y. C. V-2097.

ELECTRICAL ENGINEER with experience on electrification of textile mills. Man about 28-30 years of age for resident engineer on job to supervise installation. Application by letter. Salary not stated. Location, N. Y. and vicinity. V-2106.

DISTRICT SALES MANAGERS for company manufacturing automatic solenoid flashers. Application by letter. Salary not stated. Location, New York City. V-2108.

SALES ENGINEERS, three of these men are to possess the qualifications requisite to apply gas fired steam boilers in industries and also for house heating. One for application of gas fired appliances for heat treatment of metals and one to possess qualifications for application of gas to gas-burning equipment to large bake ovens. Application by letter. Location, N. Y. V-2110.

ELECTRICAL ENGINEERS with G. E. or Westinghouse test floor experience supplemented by road work and office report training to act as inspectors for insurance company. Must know insulation, windings and electrical equipment. Application by letter. Location, various. V-2119.

ENGINEER interested in design and construction of rotating electrical apparatus to take up designing with manufacturing company. Experience highly desirable. Technical training essential. Application by letter stating training and experience. Salary dependent upon ability and experience. Location, Pa. V-2136.

ENGINEERS having some selling experience to dispose of the Scientific Fuel Saver which is a Patented draft control sold under a guaranteed saving of 10% or more of fuel. Application by letter. Salary not stated. Headquarters, New York City. V-2137.

EXPERT BOILERMAKER FOREMAN thoroughly experienced in all practical phases of standard boiler construction, familiar with A. S. M. E. boiler, code layout of templates for shell plates, heads, crown sheets, etc. Must thoroughly understand process of bending, flanging, scarfing, etc., and be able to make quick survey for repairs and reasonable estimate on time to do the work. Application by letter. Salary not stated. Location, Ohio. V-2138.

SALESMAN broadly experienced on lighting fixtures. Application by letter. Location, Jacksonville, Fla. V-2139.

INSPECTORS on automatic telephones, switchboards, etc. Application by letter. Location, N. Y. C. V-2158.

ENGINEER throughly versed in power plant lubrication to take charge of technical work in Italy. Must be native born Italian with American training. Man 30-40 years old, having had power plant experience. Application by letter. V-2167.

HEATING & VENTILATING DRAFTSMAN on power plant. Must also have plumbing experience. Application in person. Location, New York City. V-2172

YOUNG ELECTRICAL ENGINEER capable of handling service correspondence, making tests and compiling data. Application by letter stating experience and salary expected. Location, Wisconsin. V-2171.

INDUSTRIAL GAS APPLIANCE SALESMAN. One who is a business getter, and can bring in results. Contemplate opening an industrial department and want first class man who would be willing to create and make this department what it should be. Application by letter. Salary not stated. Location, Virginia. V-2173.

ENGINEER experienced in estimating water tube boilers and heavy plate work. Excellent opportunity for advancement to engineering department. Application by letter. Salary not stated. Location, Missouri. V-2174.

FOREMAN—Dry press shop. At present department employs 40-50 persons. Must have had experience in dry-pressing of porcelain. Position eventually leads to superintendency of plant. Age 30-35; technical education not essential, but experience is. Application by letter. Salary depending on experience of applicant. Location, Ill. V-2179.

HIGH CLASS ELECTRICAL SALES REPRESENTATIVES for reliable concern manufacturing carbon, graphite, electro-graphitic and metallic brushes for motors and generators, also general line of carbon specialties. Exclusive rights given to each of territories on liberal straight commission sales proposition. Specify in detail past engineering and sales experience. Territories Chicago vicinity, St. Louis, Birmingham, Washington, D. C. and San Francisco. Headquarters, N. Y. V-2184.

SALESMAN with knowledge of coal combustion for heating and power plant, to sell fuel economy apparatus, designed to burn buckwheat coal and screenings in plants where large and more expensive coal is used. Application in person. Commission basis. Location, Philadelphia, Pa. V-2191.

ENGINEER familiar with steam and hot water heating and general piping, to estimate, lay out and superintend. Some acquaintance with Philadelphia architects and engineers desirable. Application in person. Location, Philadelphia, Pa. V-2192.

GRADUATE ELECTRICAL ENGINEERS (2) or DESIGNING DRAFTSMEN, with 2-5 years experience on electrical apparatus, such as substations and switchboard designing, public utilities organization. Application by letter. Salary $150. Location, Pa. V-2193.

DESIGNING ENGINEERS (6) graduate electrical engineers required for substation and switchboard designing, public utilities central station work. Application by letter. Location, Pa. V-2194.

DESIGNING DRAFTSMAN, graduate electrical engineer. Must be good letterer. Send sample of drawing with application, central station. Application by letter. Location, Pa. V-2195.

APPRENTICE AND ASSISTANT TEST ENGINEERS, Mechanical Engineering graduates, for testing turbines, pumps, condensers. Central station plants. Application by letter. Location, Pa. V-2196.

SUPERINTENDENT of foil plant with rolling mill experience. Application by letter. Salary not stated. Location, New York City. V-2197.

DESIGNER with experience on carbon circuit breakers and other control devices. Technical man preferred. State age, experience and salary expected. Location, Pa. V-2206.

1922 MECHANICAL ELECTRICAL ENGINEERING GRADUATES, desirous of taking training course in construction and erection work. Must be Americans, aggressive and of strong physique. Application in person. Location, N. Y. C. V-2207.

HEAD DRAFTSMAN for architect's office. Application by letter. Salary not stated. Location, Arkansas. V-2210.

TIME STUDY ENGINEER with about 5 years experience. Duties will be on loading and other labor problems. Application by letter stating age, experience, etc. Salary not stated. Location, N. Y. C. V-2214.

DESIGNER for new types of circuit breakers. Must be thoroughly experienced in this line of work. Must be able to redesign or make improvements on present designs. Only men with this experience considered. Application by letter stating age, education and experience. Salary not stated. Location, N. Y. C. V-2216.

YOUNG ENGINEER with experience in tinsel plant if possible. Must be aggressive and have knowledge of the trade. Application by letter stating age, education and experience. Salary not stated. Location, Mass. V-2217.

DESIGNER familiar with dental equipment and dental tools. Application by letter. Salary not stated. Location, New York. V-2220.

GRADUATE ENGINEER, preferably with Mechanical Engineering degree to teach Elementary Mechanics to first year engineering students. Should have had some successful teaching experience either in college or in public school. Public School experience is just as desirable as the former. Application by letter. Location, Texas. V-2222.

RADIO ENGINEER for well established manufacturing firm. Graduate electrical engineer experienced in theory, design, and manufacture of radio equipment. Application by letter giving full details as to experience, salary required, etc. Location, Mass. V-2233.

ENGINEER to take charge of new business department in corporation managing public utilities. Must have had 4 or 5 years experience in this work. Over 30 years of age. Application by letter. Location, New York City and traveling. V-2234.

ELECTRICAL ENGINEERS (3) with 3-5 yrs. experience in design, estimating and construction and distribution system of public utility. Opportunity for advancement to responsible position as departmental head. Application by letter. Location, Eastern U. S. V-2265.

YOUNG TECHNICAL COLLEGE GRADUATE M. E. or E. E. with writing experience. Duties will be to write catalogues and circulars on motors and application of motors to various industries. Should have had experience at technical writing. Application by letter. Salary not stated. Location, Pa. V-2251.

SALESMAN, experienced and aggressive, familiar with automobile line, thoroughly dependable and reliable. Application by letter. Salary not stated. Location, Ohio. V-2259.

HIGH TENSION SWITCHBOARD OPERATORS. Application in person. Location, Peru. V-2270.

AGENTS to handle sale and installation of Newport Rotary Oil Burner, an oil burner burning efficiently 11 deg. baume Mexican Oil for high and low pressure steam and hot water boilers. Exclusive territory granted. Application by letter. Salary not stated. Headquarters, Rhode Island. V-2274.

INSTRUCTOR in General Engineering Drawing, including descriptive geometry. Only graduates of recognized technical schools considered. Teaching experience desirable but not essential. One or two years of practical engineering experience necessary. Must have good personality, be enthusiastic and suited by aptitude to teaching work. Application by letter. Location, Illinois. V-2276.

ENGINEER familiar with machine tool industry and application of motors and control to machine tools of all kinds. Thorough technical training and must be able to meet people outside and willing to spend part of time traveling among customers. Application by letter. Salary not stated. Familiarity with control especially desirous. Headquarters, Pa. V-2277.

REFRIGERATING SALES ENGINEER. Excellent opportunity for thoroughly experienced refrigerating engineer to travel in Western territory for old reliable manufacturer. Only those who can point to a successful sales record need apply. Application by letter giving qualifications. Salary not stated. Location, Omaha, Neb. V-2283.

ENGINEER, with two years planning experience to schedule jobs. Application in person. Location, New York City. V-2285.

MAN experienced in teaching in manual schools. Two years contract. Must be college man. To teach trades to children in Russia and Asia Minor. Application in person. Headquarters, New York City. V-2287.

RECENT MECHANICAL ENGINEERING GRADUATE to train for position of assistant

superintendent. To look after power house, piping and installation. Must be aggressive and willing to work. Application by letter. Salary not stated. Location, N. J. V-2294.

YOUNG ENGINEER E. E. or M. E. experienced in the use and application of auxiliary for high pressure modern steam power plants. Ability to write advertising copy and prepare technical articles for press essential. Company manufactures electrical valve control equipment used exclusively on steam lines in large power stations and also complete line of valve control apparatus for water works and power stations. Will also act as research engineer for new fields for control and must possess sufficient business and engineering knowledge to carry on work without supervision. Prefer married man, age not over 35 or 40, already in a similar position. Application by letter. Salary not stated. Location, Conn. V-2302.

FIRST CLASS DESIGNER ENGINEER AND DRAFTSMAN. Must be technically prained and have had some experience. Application by telegram stating age, education and exterience. Location, Oklahoma. V-2303.

ENGINEER capable of doing some editorial work for *Marine Review*. Some practical experience at sea, in shipyards, or preferably in office of well organized ship operating company desirable. Should have had at least 5 years practical experience. Experience as technical journalist desirable but not necessary. Ability to write absolutely essential. Must be familiar with American shipping. Application by letter. Location, Ohio. V-2308.

INDUSTRIAL ENGINEER for professional work with experience in industrial management including time and motion studies, wage setting, planning and routing. Should have pleasing personality with full appreciation of human factor and should be able to gain confidence of clients as well as the men in shop, including foreman and superintendents. Must have natural inclination for industrial engineering. Application by letter. Salary not stated. Location, Wisconsin. V-2314.

ELECTRICAL APPLIANCE SALESMAN, experienced. Application in person. Location, New York City. V-2315.

GRADUATE ELECTRICAL ENGINEER for engineering dept. of trunk line R. R. Must be able to design, prepare plans, and specifications for lighting, power, fire alarms, systems, etc. for various R. R. properties. Elevator conveyor, etc. experience desirable. Application by letter stating age, education and experience. Salary not stated. Location, New York City. V-2320.

INSTRUCTOR to teach heat, power engineering, engines, boilers, industrial engineering, heating ventilation and machine design. Must have college degree. Application by letter. Location, Arkansas. V-2322.

FIRST CLASS TRACER experienced on electrical work. Must be excellent letterer. Application in person. Location, Alabama. V-2325.

ELECTRICAL ENGINEER experienced on detailing generator foundations, electrical leads, conduits, etc. Must be able to make good drawing. Application in person. Location, Alabama. V-2326.

DESIGNER, experienced on centrifugal pumps or velocity machines and reciprocating pumps, engine work, or allied lines. Application by letter stating education, experience, age, physical characteristics, compensation required and when available, in hand writing. Salary not stated. Location, Mass. V-2328.

ELECTRICAL ENGINEERS OR MECHANICAL ENGINEERS (2) with sales experience and preferably G. E. testing floor experience to handle sale of carbon brushes. Will be given three months training course at factory in Mid-West. Clean-cut Americans of 30 years and good personality desired. Application by letter. Salary not stated. Location not stated. V-2354.

MECHANICAL DRAFTSMAN with experience on gasoline engine detail design. Application by letter. Salary not stated. Location, Iowa. V-2355.

SALESMAN. Territory restricted. Good proposition for man with technical knowledge who wishes to break into sales game. Application by letter. Salary not stated. Location, Buffalo, N. Y. V-2357.

SALES REPRESENTATIVES for new concern manufacturing steam turbines. Preference given to men having one of the following qualifications; 1. Graduate mechanical or electrical engineer. 2. Experienced in steam turbine design, manufacture or sales. 3. Established as representative at present of some other concern selling pumps or power-plant contractor. Application by letter, giving qualifications and references. Commission basis. Location, Philadelphia, Pittsburgh, Cleveland, Chicago, New Orleans, Kansas City and St. Louis territories. Headquarters, New York State. V-2358.

SALES ENGINEER to sell service of Contracting Company. Application by letter. Salary not stated. Location, New Jersey. V-2363.

GENERAL MANAGER for thoroughly established engineering company. Must have thorough understanding and working knowledge of combustion as it relates to high pressure boilers and their operation. Must possess more than average ability and positively be financially able to invest $25,000 in company. Will be given definite authority in controlling company's operations and business policies. Additional inducements presented at interview. Write fully. Information furnished confidential. Salary not stated. Location, Ohio. V-2373.

ENGINEER to handle technical writing and advertising work. Must be experienced in technical and electrical practises, to write service instructions and technical descriptions, also to prepare advertising copy. Application by letter giving age, full details of past experience, salary expected, and date available. Location, N. Y. State. V-2375.

ENGINEER to represent company in making contracts with industrial concerns for installation of a training program for foremen. Must have selling experience. Part time basis considered. Application by letter. Commission basis. Location, N. Y. C. V-2379.

ASSISTANT TO POWER SUPERVISOR. Young man 30-35. General knowledge of power and electricity. Application by letter. Location, Buffalo, N. Y. V-2385.

YOUNG MAN, college graduate in engineering, preferable one who has had a year or so experience working. Should have the qualifications to make a good salesman, be able to speak Spanish and be willing to spend, if necessary, nine months of the year traveling in Cuba. Application by letter. V-2438.

SALES ENGINEERS. Should be naturally good order closers, able to figure power required. One man familiar with compressed air, small electric motors, and automatic control systems; one for small high pressure water pumps for suburban and public building trades, architects, etc. One for exclusive line of short belt drive idler systems. Automobile necessary. Commission basis, 12-½%. No advances. Application by letter. Headquarters, Los Angeles, Cal. V-2444.

SOLICITOR for electric services. Duties will be principally in lighting and some small power applications. Prefer college graduate with two or three years experience with a central station. Want someone who can develop with the company and who will show an aptitude for work. Must possess selling qualifications and be a good mixer and have a good personality. Application by letter. Salary $150. Location, Pa. V-2451.

ENGINEEEING SALESMAN. Good opportunity for young electrical engineering graduate to establish with a large electrical manufacturing concern as a sales engineer. Application by letter stating important particulars in first letter. Salary not stated. Location, central. V-2526.

MEN AVAILABLE

MANUFACTURING METHODS ENGINEER who understands bonus systems, mass-production methods, and industrial management, desires permanent connection with small manufacturing company in middle west. College graduate in Electrical Engineering with electrical design and construction experience. Will consider technical or semi-technical work in engineering or production departments. E-3524.

GENERAL MANAGER. Over twenty-years experience in construction, operation, management of public utilities. General manager large railway, gas and power company prior to the war. Know the business from the coal pile to the public. Successful executive, energetic and tactful. Age 47, married, American, several years experience abroad, speak Spanish. Available now. E-3525.

ELECTRICAL ENGINEER. Technical graduate experienced in all phases of construction work, nine years laboratory testing, steam, marine and shop experience. Desires position with consulting engineering concern, manufacturer or contractor for estimating construction and follow-up work, familiar with office and soliciting work. Location preferred New York City district. E-3526.

MECHANICAL AND POWER ENGINEER technical graduate, B. S., M. E. eight years broad experience, machine shop, metallurgy, sugar engineering, industrial and power plant practise operation, design layout, calculations, heat balance, utilization and distribution of steam, water, coal, power, etc., investigation, research reports. Executive and business ability. E-3527

SALES ENGINEER technically educated, age 28, married, desires to make connection with an electrical or mechanical sales organization, five years in manufacturing and sales. At present employed as sales engineer with large merchandizing organization in mechanical equipment Associate A. I. E. E. Desires permanent connection with reliable firm. E-3528.

GRADUATE ELECTRICAL ENGINEER. Eight years engineering experience with public utilities in transmission, distribution, sub-station design and construction; desires an opportunity in power sales bureau of utility company in sales work. E-3529.

ELECTRICAL ENGINEER. Practical and technical engineer with nine years experience as assistant to chief electrical engineer of large manufacturing company with 500,000 horse power connected load. Familiar with design and installation of substations, power plants, wiring of all kinds, motor drives, estimating, supervising installations and purchasing. Change desired as present work requires traveling. Location desired anywhere in U. S., middle west, far west or south. Will consider work as outlined above, production or plant engineering. Excellent references. Available one month. E-3530.

ELECTRICAL ENGINEER, technical graduate of University, Assoc. A. I. E. E. Age 24. Three years experience in design and construction of power plants and substations. Now with large power company but desires connection with company offering opportunity for advancement. E-3531.

INDUSTRIAL ELECTRICAL ENGINEER, COST ACCOUNTANT, AND STATISTICIAN, having eleven years experience in the theory, design, estimating and manufacture of the insulated wire and cable industry, desires a position with some public utility or any other enterprise offering a future, where above experience will prove mutually beneficial. Location, N. Y. City or vicinity. E-3532.

ELECTRICAL ENGINEER, technical graduate. Assoc. A. I. E. E. Age 33. 4 years experience, hydro-electrical construction. 4 years with industrial plant, 2 years public utility. Desires permanent position with well established company. Location preferred East, available one month. E-3533.

ELECTRICAL GRADUATE, 7 years industrial and power plant design, and supervision. Desires connection as sales engineer, or as executive on electrical design or manufacture. E-3534.

TECHNICALLY EDUCATED MAN—age 23, 2½ years of practical experience, consisting of testing and inspecting of numerous types and makes of electrical instruments, transformers, relays, circuit breakers, etc., selling; four years college, electrical engineering, would consider a worthwhile proposition with a well established company. E-3535.

TRANSMISSION LINE ENGINEER. Six years experience in the design of all types of transmission line construction with special reference to mechanical and structural problems. Also one year in test department of a large concern manufacturing electrical machinery. University graduate. E-3536.

MECHANICAL AND ELECTRICAL ENGINEER desires to change position. At present executive head of design, construction and operations of electrical and hydraulic work. Advisatory mechanical engineer for large corporation. Have built five power plants in the past twelve years for the same company. Correspondence confidential. E-3537.

MECHANICAL ENGINEER, 15 years experience negotiating power plant and special machinery. Industrial plants; organization, management and sales. Location New York. E-3538

SOON AVAILABLE — TECHNICALLY TRAINED ENGINEER who has had great variety of work for a telephone company and at present for a bureau of public utilities, handling relations between city and utilities companies. Can handle investigations, valuation or sales. Graduate engineer, degree M. E., but most work has been electrical. E-3539.

ELECTRICAL SALESMAN with technical education wishes agency for state of Texas. Would consider either industrial electrical equipment or line of specialities. E-3540.

WANTED, POSITION AS FACTORY MANAGER, GENERAL SUPERINTENDENT or INDUSTRIAL ENGINEER with a live and progressive firm where initiative, tact and common sense will be appreciated. Member; 40 years of age, Technical education and eighteen years experience in engineering and manufacturing in metal and wood. Location optional, salary reasonable. E-3541.

TECHNICAL GRADUATE, B. S. in E. E., Enrolled student A. I. E. E., age 25, single. Desires a position in the construction game or where my services can be best utilized. Experience, one year illuminating engineering and estimating; ½ year motor production and 1¼ years storage battery work. Available immediately, location immaterial. E-3542.

ELECTRICAL ENGINEER, 32 would like to connect with a large electrical company having foreign interests. Can speak, read and write English, German, Dutch fluently. Have travelled extensively in Germany, Belgium, Holland, French and the Dutch East Indies. E-3543.

TECHNICAL GRADUATE. Assoc. A. I. E. E., age 33. Completed Westinghouse Graduate Students' Apprentice Course, East Pittsburgh, Pa. Ten years' experience in railway, light and power work, both commercial and operating. Desires position as assistant commercial engineer, with public utility, either railway or power company, Now with large power company. E-3544.

ELECTRICAL ENGINEER, Technical Graduate; Assoc. A. I. E. E. Age 33, nine years experience in metering and testing. At present foreman of meter test. Desires permanent position as meter department superintendent or assistant superintendent. Can also give service to consumers in lighting and power applications. Location preferred, New York State. Reasonable salary expected. Available January 1st. E-3545.

ELECTRICAL INSTRUCTOR desires a position teaching in vocational or technical school. Can teach systems of wiring of d. c. and a. c. high and low voltages, illumination and some machine shop work. Age 25, over 6 years experience in wiring for light and power, storage batteries, steel mill and power station work. Assoc. of A. I. E. E. and I. E. S. Location N. Y. or Penn. E-3546.

STEEL MILL ELECTRICAL ENGINEER Technical graduate, 1912. Thoroughly familiar with selection, installation, and operation of modern motor and control applications, and power generation. Desire permanent executive position with progressive steel plant or similar organization. Pittsburgh or Philadelphia districts preferred. Age 33. Married. Member A. I. & S. E. E., Associate A. I. E. E. At present employed. E-3547.

ELECTRICAL ENGINEER, unmarried, 28 years old, extensive experience in industrial construction and maintenance, wire and cable testing, design of electric heating appliances, desires opportunity with future possibilities. E-3548.

GRADUATE ELECTRICAL ENGINEER, B. Sc., Assoc. A. I. E. E., 26, desires position either as sales engineer or radio engineer. Some sales experience and two years experience in the installation, maintenance and repair of radio telephones for the U. S. Navy. At present employed in an engineering capacity but could be available at a short notice. Location, New England preferred, preferably Boston or vicinity. E-3549.

EXPERIMENTAL ENGINEER AND INVENTOR of marked originality and initiative desires permanent connection with concern having broad interests in developmental lines. Opportunity for advancement essential. M. E. and M. S. in E. E., age 32; varied experience in testing, design and experimental development. Can terminate present employment at will after Nov. 1. New York City preferred. E-3950.

SALES ENGINEER. Electrical graduate. Associate A. I. E. E., Alexander Hamilton Institute. Age 30, married. 10 years experience, leading electrical manufacturer in nearly every branch of manufacture and design. Four years sales engineer for electrical manufacturer in N. Y. City. Prefer permanent sales engineer position with future. Salary not primary object. Available 30 days. E-3951.

ELECTRICAL ENGINEER Age 42, married, 23 years experience; testing, construction, design, engineering, operation of street railway car equipment, general engineering and sales experience on electrical apparatus for coal towers, ore bridges, skip hoists. Want permanent position with street railway or conveying machinery manufacturer. Available 30 days. E-3952.

ELECTRICAL ENGINEER, broad manufacturing and production experience. Six years charge of test department. Two years designing a.-c. motors. Ten years teaching experience. Over four years engineer and works manager (present position) of manufacturer of electromechanical devices including radio apparatus. Desires similar position with small progressive company. Best references. Member A. I. E. E. E-3953.

ELECTRICAL & MECHANICAL ENGINEER, experienced in electrical and mechanical operation and maintenance of industrial plants. Thoroughly familiar with contracting work and steam plants. Now available. E-3954.

ENGINEER, age 26, degree Electrical Engineer, three and one-half years experience with consulting, construction, or operating concern in middle-west. Outdoor work preferred. E-3955.

ENGINEER, graduate electrical, age 29, married, experience in the manufacture of electrical apparatus, several years experience as sales engineer and branch office manager, also some experience in development work. Available in 30 days. Desires position with opportunity for advancement. E-3956.

MANAGER OR SUPERINTENDENT, Graduate Electrical Engineer with twelve years experience in transmission distribution, construction, gas and electric sales, rate matters and management of public utilities wants change of location. Tactful with public, can furnish best of references. Married. Middle West preferred. Member A. I. E. E. and A. S. M. E. E-3957.

ELECTRICAL ENGINEER or ELECTRICAL SUPERINTENDENT. Industrial plant or steel mill. Nine years, operation, testing, engineering experience public utility and industrial plant. Capable of layout of industrial motor and control applications, and power plant equipment. Thoroughly interested in problems of production and power costs. Technical education with operating experience. Age 32. Married. E-3958.

CHIEF ENGINEER or SUPERINTENDENT in electric furnace plant. High ability, thorough training in mathematics, physics and electro-chemistry. Two years experience in general engineering, five years in electrical machine design, seven years in electric furnace practise. Minimum salary $4500. E-3959.

ELECTRICAL SUPERINTENDENT with twenty-two years practical experience, sixteen years executive on location, design, construction and operation electric railway and power properties, desires connection leading to permanent position. Natural ability for organization and working men to best advantage. Forty years of age, and married. Available now. E-3960.

CHIEF ELECTRICIAN or ASSISTANT IN INDUSTRIAL PLANT. Age 38, married. Twenty years' practical experience, maintenance, operation and construction; three years' technical education. Central States preferred. E-3961.

ELECTRICAL ENGINEER, university graduate, 35, with 10 years of valuable experience in America, Europe, Australia and the Orient, specialized in economic steam power production with low grade fuel, further experience consisting of construction, street car-system operating, testing (G. E. test) and commercial, having thorough knowledge of French and German, desires permanent position, preferably in U. S. or Canada. E-3962.

TECHNICAL GRADUATE (29) desires position with manufacturing or operating company. Eighteen months G. E. test, experience in synchronous converter design, storage batteries, starters. Future rather than salary desired. No miracle worker but ability and stick-to-it-iveness to push the job. Employed. Available reasonable notice E-3963.

GRADUATE ELECTRICAL ENGINEER, M. I. E., 1915, seven years broad experience in testing, maintenance and service work, desires position in service or application work or as assistant superintendent or assistant to chief engineer of power company or large industrial company. E-3964.

EXECUTIVE AND SALES ENGINEER, with experience in development and application of electrical power apparatus. Desires position with manufacturing company, as representative or sales agent for electrical equipment. Associate A. I. E. E. Territory preferred middle west. Available at once. E-3965.

TECHNICAL GRADUATE OF E. E. Have had four years experience in maintenance work; three years in the manufacture of dry batteries; one and one-half years in repairing electrical appliances. Education self-acquired. Desires position with power company, or industrial plant in Eastern States. Available on two weeks notice. Age 26. E-3966.

EXECUTIVE. Graduate Electrical-Mechanical Engineer. Fifteen years commercial experience, export, import, management, organization, executive. Six years Europe, three years Asia, six United States. Perfect education. Speaks fluently six languages. Director large American company. Available for executive responsible position. Salary $15,000 per year. Commercial or banking line preferred. E-3967.

YOUNG MAN, 21, general practical electrical experience. Three years estimating, wiring,

contracting, and city inspector in North Carolina, also full graduate N. Y. Electrical school, specializing in radio assembling and electrical construction. Talent for inventing elctrical contrivances. Assoc. A. I. E. E. Want position with opportunity for promotion as I am destined for a lifetime executive position with corporation willing to try me out as active working assistant around $2400 a year. E-3968.

ELECTRICAL ENGINEER. Age 32. Member A. I. E. E., A. I. & S. E. E. 14 years extraordinary electrical and mechanical experience, as executive and otherwise, with largest industrial plants, central stations and contractors, embracing high-tension transmission, electrical precipitation, electrometallurgy, automatic and remote controlled bridge, gantry cranes, skip hoists, locomotives, turbines, industrial power and lighting layouts. Can handle men and work demanding organizing ability. Was a recent Elec. Engr. of a large industrial plant. Present connection too limited. Desires connection as engineer, supt. or manager. Preferably West but not essential. E-3969.

GRADUATE ELECTRICAL AND MECHANICAL ENGINEER, 36, fifteen years experience. Last seven years with large contracting and designing engineering company in charge of design of electrical installations for industrial plants. Best of references. Desires connection with firm offering permanent position and opportunity for advancement. Speaks Scandinavian languages. Salary $5000.00. E-3970.

MEMBERSHIP — Applications, Elections, Transfers, Etc.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates or election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before September 30, 1922.

Angermann, Paul Richard, Clifton, N. J.
Aster, Alvin K., New York, N. Y.
Barr, George Daniel, Greenville, S. C.
Bowers, Zonnie P., Memphis, Tenn.
Bressler, John W., Newark, N. J.
Brewster, Walter S., Perth Amboy, N. J.
Campbell, Roy J., Pittsburgh, Pa.
Chironna, John, New York, N. Y.
Clarke, Lionel C., Colton, Calif.
Compton, Earl E., Dayton, Ohio
Conley, Harry Vincent, Pittsburgh, Pa.
Cope, A. N. (Member) Columbus, Ohio
Councill, Francis W., Washington, D. C.
Cullen, Robert E., New York, N. Y.
Cusato, Louis S., Pittsfield, Mass.
Davis, Tolbert J., Patton, Pa.
Douglass, Holmes T., New York, N. Y.
Dunsen, Bernhard, New York, N. Y.
Eddy, Levi C., Milwaukee, Wis.
Ellis, Paul Carlton, Excelsior Springs, Mo.
Freeman, George, Brooklyn, N. Y.
Garrison, Fred, Schenectady, N. Y.
Gildersleeve, Gordon Hamilton, Schenectady, N.Y.
Goodman, Aaron, New York, N. Y.
Gremlich, Edwin, Beacon, N. Y.
Groeneveld-Meijer, Nicolaas Everhard, Schenectady, N. Y.
Haas, Cecil Irving, Schenectady, N. Y.
Hewlett, Frank Gurley, (Fellow), Allison (Greene Co.,) Alabama.
Hill, Leland H., Wilkinsburg, Pa.
Hubbard, Alfred M. (Member), Pittsburgh, Pa.
Hughes, Thomas W., Sheridan, Wyo.
Krause, Emil, New York, N. Y.
Ladwig, William J., Milwaukee, Wis.
Lawson, Alfred W., Brooklyn, N. Y.
Locash, Charles, New York, N. Y.
Longboat, Hermon, New York, N. Y.
MacKay, Roberts F., Vancouver, B. C.
Mackey, Brentford R., New York, N. Y.
Martin, Victor G., Rochester, N. Y.
McAnge, William Norman (Member), Corinth, Miss.
Moravac, James E., New York, N. Y.
Mott, Harold E., Westmount, Canada.
Myrick, Samuel Edward, Atlanta, Ga.
Norman, Olaf Alexander, Milwaukee, Wis.
Nottingham, Wayne B., New York, N. Y.
Pacey, Guy H., West Lafayette, Ind.
Patton, Harold S., Chicago, Ill.
Pease, Edgar R., New York, N. Y.
Peck, Arthur David, (Member), Chicopee Falls, Mass.
Pereira, Richard G., New York, N. Y.
Plenge, Edward B., Scotia, N. Y.
Porter, Vance C., Bay City, Texas.
Poulson, George C., New York, N. Y.
Powell, George W., Milwaukee, Wis.
Ragsdale, Randolph D., Dannemora, N. Y.
Ransom, Ferdinand, Brooklyn, N. Y.
Remington, George W., (Member), Philadelphia, Pa.
Richardson, Albert H., Erie, Pa.
Richfield, Nicholas, New York, N. Y.
Robinson, James W., New York, N. Y.
Romweber, Harold E., Cleveland, Ohio.
Rudin, George C., Bronxville, N. Y.
Sandak, Harry M., New York, N. Y.
Schmidt, A. Gero, Highwood, N. J.
Schweighofer, Joseph, Jr., New York, N. Y.
Sieger, Charles M., Catasauqua, Pa.
Smith, Leroy, Oil City, Pa.
Steinmetz, Richard B., Brooklyn, N. Y.
Summerville, Joseph A., Boston, Mass.
Teichner, William, New York, N. Y.
Troesch, Walter Robert, New York, N. Y.
Tullar, Charles E., Schenectady, N. Y.
Walsh, Thomas H., (Member), Devon, Conn.
White, Allen O., Washington, D. C.
Withington, William Gutelius, Washington, D. C.
Young, John Warren, Scranton, Pa.
Total 75.

Foreign

Brostrom, Carl, Lima, Peru.
Cudebec, Albert B., (Fellow), Paris, France.
Horioka, Masaie, Tokyo, Japan.
Knaur, Richard T., Vienna, Austria.
Kulske, R. H., (Member), Cape Town, South Africa.
Nisbet, Carrick, Hamilton, New Zealand.
Patel, P. E., Bombay, India.
Paulsen, Alfred G. (Member), Yucatan, Mexico.
Pillay, Padmanabha S., Cochin, S. India.
Press, Ernest E., Cape Town, S. Africa.
Robertson, John, Belfast, Ireland.
Spurling, Walter Everard, (Member), Pembroke Parish, Bermuda Islands.
St. Martin, Algernon S., Chaba, Simla, N. India.
Total 13.

LIST OF SECTIONS

Name	Chairman	Secretary
Akron	S. C. Henton	A. P. Regal, Phila. Rubber Works Co., Akron, O.
Atlanta	J. E. Mellett	H. N. Pye, Box 1743, Atlanta, Ga.
Baltimore	W. B. Kouwenhoven	F. T. Leilich, 550 Lexington Bldg., Baltimore, Md.
Boston	E. L. Moreland	F. S. Dellenbaugh, M. I. T., Cambridge, Mass.
Chicago	F. E. Goodnow	J. E. Kearns, General Electric Co., Monadnock Block, Chicago, Ill.
Cincinnati	A. M. Wilson	C. G. Eichelberger, Union Gas & Elec. Co., Cincinnati, O.
Cleveland	L. D. Bale	Chester L. Dows, Nela Park, Cleveland, O.
Columbus	F. C. Caldwell	F. C. Nesbitt, Huntington Bank Bldg., Columbus, O.
Connecticut	E. H. Everit	A.E. Knowlton, Dunham Laboratory, S. S. S., Yale University, New Haven, Conn.
Denver	H. B. Barnes	R. B. Bonney, 603 Wyoming Bldg., Denver, Colo.
Detroit-Ann Anbor	J. H. Cannon	E. L. Bailey, 1918 Ford Bldg., Detroit, Mich.
Erie	W. J. Seibert	M. W. Metzner, General Electric Co., Erie, Pa.
Fort Wayne	S. W. Greenland	A. B. Campbell, General Electric Co., Fort Wayne, Ind.
Indianapolis-Lafayette	D. C. Pyke	J. W. Hannon, Telephone Bldg., Indianapolis, Ind.
Ithaca	J. G. Pertsch, Jr.	Geo. F. Bason, Cornell University, Ithaca, N. Y.
Kansas City	C. J. Larsen	Glenn O. Brown, K. C. Power Co., Kansas City, Mo.
Lehigh Valley	D. M. Petty	H. G. Harvey, Penna. Edison Co., Easton, Pa.
Los Angeles	J. N. Kelman	E. R. Stauffacher, 700 Edison Bldg., Los Angeles, Calif.
Lynn	J. W. West	W. M. Howe, General Electric Co., West Lynn, Mass.
Madison	H. M. Crothers	R. G. Walter, 900 Gay Bldg., Madison, Wis.
Mexico	————	————
Milwaukee	G. C. Post	F. A. Kartak, Marquette University, Milwaukee, Wis.
Minnesota	Fred A. Otto	H. W. Meyer, Northern States Power Co., Minneapolis, Minn
New York	Calvert Townley	A. E. Waller, Lawrence Park, Bronxville, N. Y.
Oklahoma	F. W. Insull	A. D. Stoddard, Box 382 Bartlesville, Okla.
Panama	F. B. Coyle	M. P. Benninger, Box 174, Balboa Heights, C. Z.
Philadelphia	E. B. Tuttle	Ross B. Mateer, Philadelphia Elec. Co., 1000 Chestnut St., Philadelphia, Pa.
Pittsburgh	E. C. Stone	O. Needham, W. E. & M. Co., East Pittsburgh, Pa.
Pittsfield	W. P. White	A. C. Stevens, General Electric Co., Pittsfield, Mass.
Portland, Ore.	D. W. Proebstel	E. F. Pearson, Northwestern Electric Co., Portland, Ore.
Providence	R. W. Adams	F. N. Tompkins, Brown University, Providence, R. I.
Rochester	G. A. Scoville	E. A. Roeser, 34 N. Clinton Ave., Rochester, N. Y.
St. Louis	C. C. Robinson	J. M. Chandlee, 1827 Pine St. St. Louis, Mo.
San Francisco	H. H. Henline	A. G. Jones, 809 Rialto Bldg., San Francisco, Calif.
Santiago de Chile	————	
Schenectady	C. M. Davis	C. W. Fick, General Electric Co., Schenectady, N. Y.
Seattle	————	E. S. Code, 3451 E. Marginal Way, Seattle, Wash.
Southern Virginia	————	————
Spokane	H. L. Melvin	E. R. Hannibal, 424 Hutton Bldg., Spokane, Wash.
Springfield, Mass.	W. A. Dick	J. Frank Murray, United Electric Light Co., Springfield, Mass.
Syracuse	R. D. Whitney	Elmer E. Strong, 614 City Bank Bldg., Syracuse, N. Y.
Toledo	Gilbert Southern	Max Neuber, 1257 Fernwood Ave., Toledo, O.
Toronto	S. E. M. Henderson	D. B. Fleming, Hydro-Elec. Pr. Comm., 190 University Ave., Toronto, Ont.
Urbana	H. A. Brown	E. B. Paine, University of Illinois, Urbana, Ill.
Utah	C. C. Pratt	C. R. Higson, Utah Pr. & Lt. Co., Salt Lake City, Utah
Vancouver	T. H. Crosby	F. W. MacNeill, Canadian General Elec. Co., Vancouver, B. C.
Washington, D. C.	L. T. Blaisdell	Roland Whitehurst, Elec. Storage Battery Co., 1823-33 L. St. N. W., Washington, D. C.
Worcester	F. J. Adams	Dean J. Locke, 125 Salisbury St., Worcester, Mass.

Total 48

LIST OF BRANCHES

Name and Location	Chairman	Secretary
Alabama Poly. Inst., Auburn, Ala.	V. C. McIlvaine	J. M. Dickinson
Alabama, Univ. of, University, Ala.	D. H. Davis	W. W. Bauder
Arizona, Univ. of, Tucson, Ariz.	R. A. Macdonald	H. A. Hillman
Arkansas, Univ. of, Fayetteville, Ark.	J. W. Booker	B. R. Askew
Armour Inst. of Tech., Chicago, Ill.	L. E. Grube	H. M. Piety
Brooklyn Poly. Inst., Brooklyn, N. Y.	H. Ladner	O. Engstrom
Bucknell Univ., Lewisburg, Pa.	F. T. Tingley	J. A. Ammerman
California Inst. of Tech., Pasadena, Cal.	O. R. Bulkley	L. J. Wells
California, Univ. of, Berkeley, Cal.	H. R. Berry	A. A. Emlen
Carnegie Inst. of Tech., Pittsburg, Pa.	W. S. Andrews	W. J. Lyman
Case School of Applied Science, Cleveland, O.	M. A. Hyde, Jr.	O. Henderson
Cincinnati, Univ. of, Cinncinati, O.	J. R. Petree	C. B. Hoffmann
Clarkson Coll. of Tech., Potsdam, N.Y.	R. L. Conboy	F. H. Fults
Clemson Agri. College, Clemson College, S. C.	J. R. Reardon	W. M. Clatworthy
Colorado State Agri. Coll., Ft. Collins, Colo.	P. Garrett	F. Ayres
Colorado, Univ. of, Boulder, Colo.	T. D. Sylvester	F. B. Doolittle
Cooper Union, New York	W. A. Colledge	A. L. Duna
Drexel Institute, Philadelphia, Pa.	D. Buchanan	R. E. Sidwell
Georgia School of Tech., Atlanta, Ga.	C. D. LeBey	E. V. Wallace
Iowa State College, Ames, Ia.	C. H. Hoper	G. L. Seaton
Iowa, Univ. of, Iowa City, Ia.	E. Paintin	P. F. Bowman
Kansas State College, Manhattan, Kans.	L. O. Sinderson	K. C. Frank
Kansas, Univ. of, Lawrence, Kans.	D. Eyer	Wm. Anderson
Kentucky, Univ. of, Lexington, Ky.	T. M. Riley	R. H. Craig
Lafayette College, Easton, Pa.	K. A. F. Pitt	L. Conover
Lehigh Univ., South Bethlehem, Pa.	E. F. DeTurk	W. F. Tait
Lewis Institute, Chicago, Ill.	E. Millison	E. R. Lindberg
Maine, Univ. of, Orono, Me.	F. Blake	C. R. Lappin
Marquette University, Milwaukee, Wis.	————	————
Massachusetts Inst. of Tech., Cambridge, Mass.	E. J. Thimmie	H. D. McKinnon
Michigan Agri. Coll., East Lansing, Mich.	E. A. Pryce	J. G. Lauffer
Michigan, Univ. of, Ann Arbor, Mich.	R. N. Olds	A. J. Martin
Milwaukee, Engg. School of, Milwaukee, Wis.	B. A. Bovee	L. F. Berg
Minnesota, Univ. of, Minneapolis, Minn.	R. H. Olson	C. L. Sampson
Missouri, Univ. of, Columbia, Mo	A. C. Lanier	F. W. Hubbard
Montana State Coll., Bozeman, Mont.	W. W. Husemeyer	R. D. Sloan
Nebraska, Univ. of, Lincoln, Neb.	O. J. Ferguson	O. E. Edison
North Carolina State College, West Raleigh, N. C.	E. E. Inscoe	O. L. Bradshaw
North Carolina, Univ. of, Chapel Hill, N. C.	W. C. Moore	R. H. Jackson
North Dakota, Univ. of, University, N. D.	C. W. Randall	Byron Hill
Notre Dame, Univ. of, Notre Dame, Ind.	V. J. Brown	W. L. Shilts
Ohio Northern Univ., Ada, O.	D. J. Wolf	H. L. Vincent
Ohio State Univ., Columbus, O.	W. M. Kellogg	O. McGinnis
Oklahoma A. & M. Coll., Stillwater, Okla.	C. S. Folk	I. T. Knight
Oklahoma, Univ. of, Norman, Okla.	Cecil Rouch	R. E. Thornton
Oregon Agri. Coll., Corvallis, Ore.	J. H. Murton	J. H. Casto
Pennsylvania State College, State College, Pa.	H. F. Pearson	J. H. Warner
Pennsylvania, Univ. of, Philadelphia, Pa.	O. W. Manz, Jr.	A. R. Horner
Pittsburgh, Univ. of, Pittsburgh, Pa.	C. A. Anderson	A. F. Robert
Purdue Univ., Lafayette, Ind.	J. F. Welch	O. T. McIlvaine
Rensselaer Poly. Inst., Troy, N. Y.	W. J. Williams	L. S. Inskip
Rose Poly. Inst., Terre Haute, Ind.	F. M. Stone	C. B. Wilson
Rutgers College, New Brunswick, N. J	C. S. Beattie	E. H. Erickson
Southern California, Univ. of., Los Angeles, Cal.	R. H. Cockfield	E. B. Heath
Stanford Univ., Stanford University, Cal.	H. E. Becker	V. Marquis
Swarthmore Coll., Swarthmore, Pa.	S. T. McAllister	E. Palmer
Syracuse Univ., Syracuse, N. Y.	E. A. Ryan	A. P. Fugill
Texas A. & M. Coll., College Station, Tex.	T. E. Keeton	R. S. Drake
Texas, Univ. of, Austin, Tex.	C. H. Marshall	F. J. Domingues
Virginia Military Inst., Lexington, Va.	J. Girand	J. E. Woodward
Virginia Poly. Inst., Blacksburg, Va.	D. P. Minichan	T. F. Cofer
Virginia, Univ. of, University, Va.	T. R. Bunting	P. L. Weir
Washington, State Coll. of, Pullman, Wash.	C. R. Studer	E. J. Leahy
Washington Univ., St. Louis, Mo.	F. W. Schramm	E. H. Burgess
Washington, Univ. of, Seattle, Wash.	J. V. Wilson	A. W. Lundstrum
West Virginia Univ., Morgantown, W. Va.	H. Chandler	W. D. Stump
Wisconsin, Univ. of, Madison, Wis.	K. B. Bohman	J. W. Smart
Yale Univ., New Haven, Conn.	E. O. Lanphier	J. T. Houck

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DIGEST OF CURRENT INDUSTRIAL NEWS

NEW CATALOGUES AND OTHER PUBLICATIONS

Mailed to interested readers by issuing companies.

Pyrometers.—Catalog 1401, 68 pp. Describes and illustrates the various types of heat measuring instruments manufactured by the Bristol Company, Waterbury, Conn.

Electric Hoists.—Bulletin 68912, 4 pp. Describes type "WX" hoists for miscellaneous uses. Built in capacities of one half and one ton. Sprague Electric Works of G. E. Co., 527 West 34th St., New York.

Gate Valve.—Bulletin 8G, 4 pp. Illustrates a regrinding swing gate valve, designed for steam pressures up to 300 lbs. per sq. in. and temperatures up to 750° F. Schutte & Koerting Company, Philadelphia.

Single-Phase Induction Motors. Bulletin 3156, 12 pp. 1/30 to 1/2 Hp. Bulletin 3180, 12 pp., "IR" repulsion start types, 1/10 to 2 Hp., for overload starting duty. The Emerson Electric Mfg. Co., St. Louis.

Automatic Temperature Control Instruments.—Catalog 85, 24 pp. Describes a line of instruments for automatic control of temperature in ovens and furnaces, applicable in many industries where processes require the maintenance of a uniform temperature. The Brown Instrument Company, Philadelphia.

Shallow Flush Switches.—Bulletins. Describe a new type of flush switch developed especially for thin partitions such as in city apartments, but also to facilitate wiring in the regular two-inch wall box wherever installed. The Arrow Electric Company, Hartford, Conn.

Circuit Breakers.—Bulletins 450 and 452. Describe Type D-18 and Type D-22 Oil Switches and Circuit Breakers, for use in central stations and industrial plants where service is severe. Cap. up to 800 amperes—15,000 volts; 1200 amperes—7500 volts. Manual and electrical remote control. Condit Electric Mfg. Company, Boston, 27.

NOTES OF THE INDUSTRY; NEW APPARATUS

The Shaw Insulator Company has removed to its new building at 148 Coit Street, Irvington, N. J.

The Mutual Electric & Machine Co., Detroit, has announced the appointment of Joseph H. Rohs as sales manager of the Apparatus Division.

The Economy Fuse & Mfg. Co., Chicago, has removed its Detroit sales office from the Majestic Building to 1528 First National Bank Building.

The Mueller Electric Company, Cleveland.—The new building of this firm at 1583 East 31st Street has been completed, and will be devoted to the manufacture of electric specialties in a larger way.

Amplifying Transformer.—A new audio-frequency transformer has been developed by the Killark Electric Mfg. Co., St. Louis, which may be used on any amplifying bulb. The net weight of the new device is fifteen ounces.

The Pure Carbon Company, Wellsville, N. Y.—The entire stock of "Fibre Graphite" brush materials originally manumanufactured by the Holmes Fibre Graphite Co. has been taken over by the Pure Carbon Company, who will market these brushes in the future.

The Brown Instrument Company, Philadelphia, has opened a Southern branch office at Birmingham, Ala., 619 Brown-Marx Building, in charge of Charles L. Saunders; and a New England branch office at Boston, 185 Devonshire Street, in charge of George Goodman.

John A. Roebling's Sons Company, Trenton, N. J.—Announcement is made that all employees who have been with the Roebling Company a year or longer, will be protected by group life insurance and pension plans. The insurance is graded according to length of service, with a maximum of $1500. The amount of pension is determined by multiplying one per cent of the average annual pay during the ten years preceding retirement by each year of service. A minimum of $25 and a maximum of $250 per month has been established. The retirement age is sixty for men and fifty-five for women.

Westinghouse Electric & Mfg. Company, East Pittsburgh.—Announcement is made of the appointment of C. W. Horn as superintendent of radio operations of the Westinghouse Company. He will have complete charge of the company's four broadcasting stations, *K D KA*, at East Pittsburgh; *W J Z*, at Newark, N. J; *K Y W*, at Chicago; and *W B Z*, at Springfield, Mass. For the present Mr. Horn will continue as manager of the Radio Division Service Department, combining these duties with those of his new position.

"Operation and Maintenance of Electrical Equipment Approved for Permissibility by the Bureau of Mines," by L. C. Ilsley, electrical engineer, has been issued by the Bureau of Mines, as Technical Paper 306.

A permissible schedule of the Bureau of Mines establishes certain minimum standards for safety; it gives details of test methods adopted to determine whether these standards have been met, and a list of charges for such tests.

Any manufacturer has the privilege of submitting his product for test in accordance with the conditions outlined in the schedules. His action is wholly voluntary, for the Federal Government has no jurisdiction as to what equipment shall be used in mines. this authority being left to the various States. When the product of a manufacturer has met the schedule requirements, he is permitted to advertise this fact and to attach an approval plate with the bureau's seal to each machine he makes that is identical in every way with the equipment tested, inspected, and approved by the bureau.

This work of approval has grown by the addition of new schedules until at present a great many mines are using one or more classes of permissible equipment, and there is still a demand for other approved apparatus in the ever-widening field of electrically operated machinery

The safety of electrical equipment of this type depends on four fundamentals, namely, (1) correct principles of design; (2) proper assembly of parts at the factory; (3) proper assembly and installation of equipment at the mine; and (4) proper operation and maintenance after installation. The first two factors are within the province of the manufacturer. The Bureau of Mines either inspects and tests several models of one product, such as electric cap lamps, or one model, such as an electric motor. If this series of tests proves satisfactory, the manufacturer is given the privilege of making other appliances, and assembling them in the same way; the approval plate he attaches is his guaranty that the equipment is identical with the one tested and inspected by the bureau. The third and fourth factors concern those who use such permissible equipment, and it is to them that this paper is mainly addressed, in an effort to show their responsibility in rendering electrical equipment safe for use in gaseous mines.

Recommendations that apply to the operation and maintenance of nearly all makes and classes of permissible apparatus are given in Technical Paper 306, which may be obtained from the Bureau of Mines, Washington, D. C.